CONSULTANT REPORT

Public Interest Energy Research
CALIFORNIA ENERGY COMMISSION

Energy-Related
Environmental Research

HABITAT AND SPECIES PROTECTION PROJECT

Gray Davis, *Governor*

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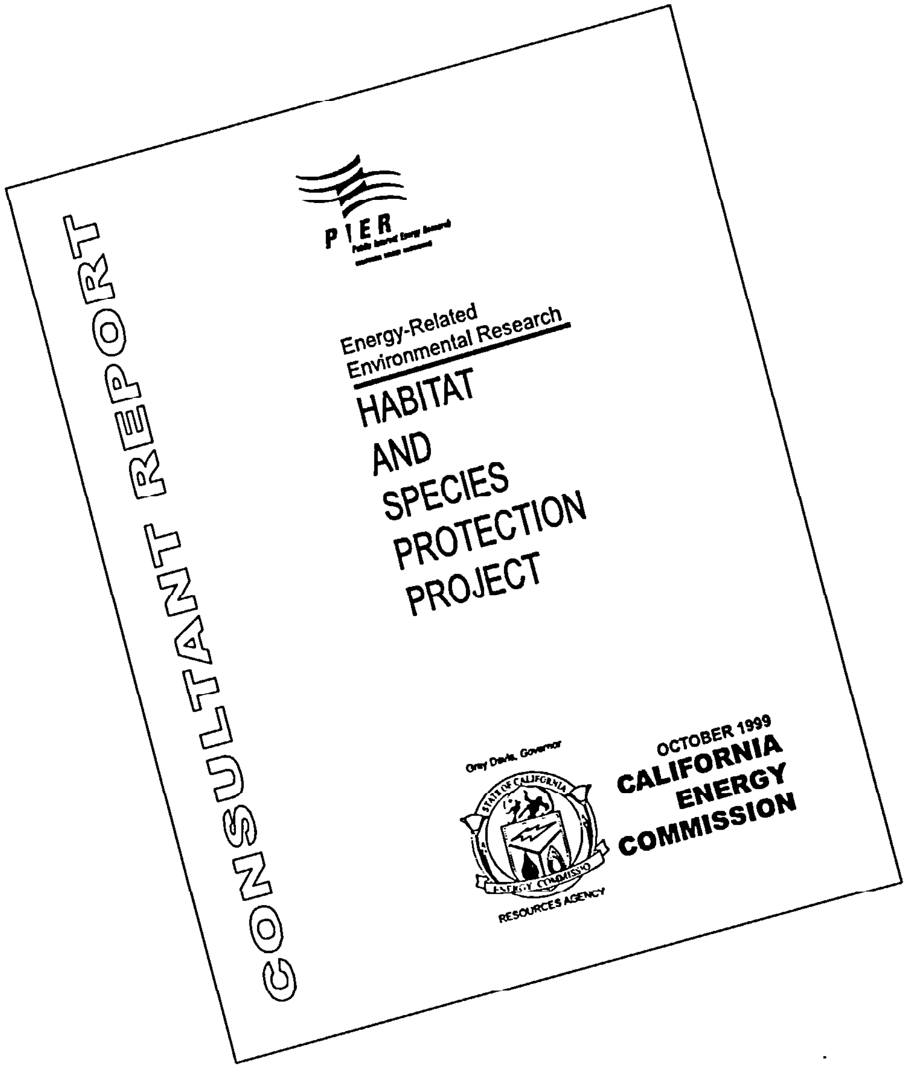

CALIFORNIA ENERGY COMMISSION

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Legal Notice

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Preface

The Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program, managed by the California Energy Commission (Commission), annually awards up to $62 million through the Year 2001 to conduct the most promising public interest energy research by partnering with Research, Development, and Demonstration (RD&D) organizations, including individuals, businesses, utilities, and public or private research institutions.

PIER funding efforts are focused on the following six RD&D program areas:

- Buildings End-Use Energy Efficiency
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy
- Environmentally-Preferred Advanced Generation
- Energy-Related Environmental Research
- Strategic Energy Research.

In 1998, the Commission awarded approximately $17 million to 39 separate transition RD&D projects covering the five PIER subject areas. These projects were selected to preserve the benefits of the most promising ongoing public interest RD&D efforts conducted by investor-owned utilities prior to the onset of electricity restructuring.

What follows is the final report for the Habitat and Species Protection project, one of five projects conducted by Southern California Edison. This project contributes to the Energy-Related Environmental Research program.

For more information on the PIER Program, please visit the Commission's Web site at: http://www.energy.state.ca.gov/research or contact the Commission at (916) 654-4628.

Executive Summary

This report presents the results of research performed as part of the Public Interest Energy Research (PIER) program funded by the California Energy Commission. The Habitat and Species Protection Research Program involves three components that seek to minimize the impacts on habitats and species from the siting, operation, and maintenance of utility transmission and distribution systems. These three components are:

- Raptor Protection Research
- Multiple Species Habitat Conservation
- California Habitat Evaluation

The Habitat and Species Protection Research program involved a number of research tasks. Some of them, while in some cases seemingly dissimilar and not related, are in fact very much related. All of the tasks have the ultimate goal of protecting endangered and otherwise sensitive species and their associated habitat in Southern California, particularly in relation to the siting, operation and maintenance of electric utility transmission lines.

Raptor Protection Research

Raptors are defined as birds of prey, such as hawks and owls. Raptor mortality due to interactions with power lines is well documented in scientific literature and in utility industry publications. Raptors are protected under several state and federal regulations.

Objectives:

- Characterize and quantify raptor use of power poles and towers as perches by surveying regions supporting particularly large concentrations of raptors during the time of year when they are most abundant.
- Search locations beneath the poles in an attempt to quantify raptor fatalities due to electrocution.
- Use this information to determine the relative risk to raptors associated with perching on power poles, as well as to determine factors influencing raptor perch selection. The results will allow poles that are likely perch sites to be made safer for raptor use.
- Evaluate the reporting procedures used in Southern California Edison’s (SCE) current Raptor Protection Program in an attempt to improve this already effective program and provide additional protection to raptors.

Outcomes:

This component of the research documented actual levels of raptor use and mortality occurring on utility power line systems and provided recommendations to reduce this mortality using methods that are both cost-effective and likely to improve system reliability. These methods may be applied to power line systems not only within Southern California Edison's (SCE’s) service territory, but throughout California to lower mortality of raptors statewide.

Conclusions:

The results of this research indicate that raptor electrocutions on SCE’s system are not as frequent as once thought. They also appear to be episodic in nature. By combining data and findings from the research performed in the Owens Valley and the San Jacinto Valley, SCE is much closer to a system-wide proactive approach to developing solutions for minimizing raptor electrocutions and overall compliance with agency regulations.

Recommendations:

- Keep the SCE database of raptor electrocutions current as new fatalities occur. Use the updated information to modify preventative measures as needed.
- Focus future efforts on the development of predictive models that both identify regions, lines, or specific poles with a high probability of raptor use by vulnerable species, and identify pole line configurations that have documented raptor electrocutions associated with them.
- Use this pre-treatment versus post-treatment fatality survey data to move toward reducing electrocutions.
- Take steps to improve SCE's Raptor Protection Program by ensuring that raptor electrocutions at SCE facilities are not under-reported.

Multiple Species Habitat Conservation Plan

For years, the development of Multiple Species Habitat Conservation Plans (MSHCPs) has been identified as a preferred mechanism for dealing with the innumerable conflicts between endangered species and sustainable economic development. With over 500 state and federally-listed species within California, the potential for conflict between these species and proposed economic development, even ongoing activities for infrastructure maintenance, is very high. One of the ways that SCE believes that this conflict can be reduced is to have MSHCPs in place that provide a mechanism for protecting multiple species and their associated habitats, that also allow for development to proceed in a controlled and predictable pattern.

The MSHCP research component directly addresses land use issues as they relate to sensitive species. Through research designed to facilitate the development of multiple species habitat reserves, this component will aid in providing protection for endangered species through an ecosystem approach at lower cost and with less conflict than the traditional species-by-species approach.

Objectives:

- Organize and conduct a workshop dedicated to facilitating the development of MSHCPs in California. Publish the results to allow others involved in developing MSHCPs to benefit from the collective knowledge and experience of the workshop participants.
- Collect data on factors affecting patterns of dispersal by California gnatcatchers. Determine what factors influence annual variation in California gnatcatcher reproductive success, survivorship, and territory size, and what the implications are for research aimed at monitoring populations of these species.
- Update the California Gnatcatcher model that was developed and published in 1997, taking advantage of the two years' worth of new data that has become available since then. Apply information about the gnatcatcher's interaction with its habitat to determine

the best method to maintain management and conservation of coastal sage scrub habitats.

- Build an assessment tool to examine potential population-level risks to the desert tortoise that would result from constructing and modifying transmission lines in the tortoise habitat.
- Develop an interactive web site that allows users to run a demo of RAMAS® GIS 3.0 software.
- Evaluate the USFWS listing protocol by comparing 60 species' risk classifications with those in a system used by the World Conservation Union.

Outcomes:

- From the workshop, recommendations were developed for improving MSHCPs. Publications of the outcomes enhanced distribution of the recommendations.
- In the coastal Orange County study sites, populations of California gnatcatchers were essentially stable from 1993 – 1998. Comparisons of survivorship estimates between Orange County and Palos Verdes failed to detect any significant difference between the two localities for adults of either sex. The same was true of juvenile dispersal distances.
- With the medium parameter estimates, the updated gnatcatcher model predicted a substantial decline, but a low risk of extinction of the gnatcatcher populations. The risk of falling below the metapopulation threshold of 30 females within 50 years was about 10%. Although the extinction risk was low, the risk of a substantial decline was high.
- The RAMAS® Ecological Risk Model makes a number of predictions. Fragmentation, habitat loss (reduction in carrying capacity) and raven predation increase the risk of a decline in abundance for the tortoise metapopulation. The results of this model suggest that the potential impacts of transmission line siting and maintenance were dependent on which populations were affected, but the effects were usually moderate. This finding supports empirical studies indicating that these populations are experiencing a large decline in abundance.
- The RAMAS® GIS website contains three sections that are launched from the main page (*index.htm*).
  - Part 1: Conservation and Management of Coastal Sage Scrub
  - Part 2: Desert Tortoise Metapopulation Dynamics (Phase II)
  - Part 3: The metapopulation model as an educational tool
- Agreement between the USFWS and the IUCN selection criteria were compared for 60 native California species. The listing status of 19 of them did not fit into corresponding categories of the IUCN and the USFWS. Eight species were listed in a higher endangerment category by the USFWS, while 11 were either not listed (9) or listed in a lower threat category (2) by USFWS.

Conclusions:

- . The information gathered at the workshop will be invaluable both in the siting of new facilities and in the management of existing facilities and rights-of-way that traverse multiple species habitat preserves.

- Because of the major time investment involved in establishing uniquely-banded populations of known-age, known-natal area birds, and the value of such a study population in addressing regional conservation issues, the Palos Verdes / Orange County (coastal) project represents a critical research element contributing to the State of California's NCCP efforts.
- It would be inappropriate to use the results of the updated gnatcatcher model to conclude that gnatcatcher populations in Central / Coastal Orange County are either threatened by extinction or secure from such a threat. There is too much uncertainty to predict with confidence what the population size will be in 50 years, or what the risk of extinction might be. Despite this uncertainty, the model can potentially have practical application in several areas. These applications also indicate future research directions.
- The RAMAS® GIS web site will serve as an excellent educational tool. It also highlights SCE's commitment to environmental research and conservation of native species.
- The inconsistent use of biological criteria and heavy reliance on qualitative variables by the USFWS result in a low correspondence with the IUCN system and with its own "degree of threat" ranking under the recovery priority listing system. The low correspondence with the IUCN categories was found in spite of the assumption that each USFWS category corresponds to two IUCN categories.
- The IUCN listing system has several advantages over the USFWS protocol. The IUCN listing process was developed under wide consultation and is recognized internationally by the public and scientific community.

Recommendations:

- Follow the recommendations determined at the workshop, some of which included:

  For the FWS:

  – Revise the HCP handbook to clarify the standards for acceptable data in plan development.

  – Provide further clarification and standardization. Establish standards for how all material used to build an HCP are referenced. Clarify the issue of "species-based" vs. "ecosystem-based" plans. Better explain the role of an HCP in recovering a species. Provide clear guidance on what constitutes acceptable mitigation from the standpoint of endangered species policy.

  – Initiate project management, especially a detailed front-end scoping of a plan.

  – Develop new funding mechanisms to increase the number of personnel available for assistance, and to expend the resources necessary to establish firm guidance for those people.

  – View lands to be developed as research tools, so that ecological experiments can be performed prior to habitat destruction.

  For creators of HCPs:

  – Ensure that plans are complete. Define the uncertainty associated with each major data set, and state specific goals and criteria for meeting them.

  - Place greater emphasis on stakeholders, including agencies, at all stages of the planning process. Provide a basic understanding of project financing.
  - Improve the planning process. Utilize planners possessing a wider range of skills, begin the planning using best land management practices, and incorporate independent peer review at each major stage of the process.
  - Each HCP should contribute to the overall understanding of ecological processes driving the HCP concept. That is, projects should be planned so that successes and failures in strategy and implementation can be documented and future projects can benefit from the knowledge.
- Conduct further fieldwork to narrow down uncertainties in the PVA model parameters, making model predictions more accurate and reliable.
- Expand the PVA model to include the populations of California Gnatcatcher in other areas.
- Use metapopulation modeling to provide guidance in reserve design, by identifying the ecological and economic consequences of each design configuration.
- Assess the effects of management actions and human impact in terms of model parameters, to determine potential consequences and rank alternative actions.
- Express the worth, in conservation terms, of a location by using the habitat-based metapopulation modeling approach on a list of selected species. Create habitat suitability maps and metapopulation models for all species in the list. Combine each of the individual habitat suitability maps into a single aggregate map.
- Conduct additional empirical studies of the tortoise, especially in the area of density dependence and predation.
- Create a new decision-making process for selection of species to protect, similar in structure to the IUCN system but modified to satisfy the specifications of the ESA.

California Habitat Evaluation

The California Habitat Evaluation research component developed operational protocols to characterize and monitor critical habitats in California using high-resolution airborne multi-spectral imagery obtained using a system called Advanced Digital Airborne Registration (ADAR). This research supported the establishment of multiple species reserves with the highest habitat values, and will aid in more timely management responses to changes in the environment.

The availability of ADAR technology to support management of preserves will not only assist SCE, as a permittee with coastal sage scrub habitat in Natural Communities Conservation Planning (NCCP) preserves, but can also assist other NCCP participants (such as San Diego Gas & Electric) as well as the regulatory public agencies (California Department of Fish & Game and USFWS). Mapping and monitoring tools also have the potential to serve conservation needs within California and beyond that are outside the regulatory purview of the NCCP. As multi-species and habitat-based conservation programs proliferate in California, the demand for cost-effective habitat management tools will increase. As a rapid, efficient method for collection of digital, landscape-level data, ADAR has the potential to provide the real-time data necessary to drive monitoring and management tools such as RAMAS® GIS 3.0 and other metapopulation models. Development of mapping and monitoring tools through this research lays the groundwork for a wide range of capabilities that comprise the toolbox for managing California's legacy of habitat preserves.

Objectives:

- Enlarge the mapping capabilities of ADAR methodologies to include numerous habitat types not previously established within the technology's repertoire, in order to better understand the limits and capabilities of ADAR as a mapping tool.
- Examine the feasibility of detecting changes in habitats over time, based on multi-date ADAR imagery.
- Describe the relative costs and benefits of using ADAR for mapping and monitoring compared to using conventional mapping methods.
- Synthesize the procedures employed in the various tasks and case studies of this research, and present them in a well-documented format to be used as a Procedures Handbook by SCE's GIAS Laboratory staff.

Outcomes:

During this task, the applications of the ADAR tool were expanded to other habitat types and tested, and work was continued on existing areas.

- Classification of habitat types based on ADAR image data was achieved with a satisfactory degree of accuracy for both the Hidden Ranch and Etiwanda sites. At the Hidden Ranch site, differences between the map produced by field biologists (conventional methods) and ADAR classification are mostly attributable to standard sources of error: mapper subjectivity, image displacement, and limited field verification.
- Because ADAR-based classification is computer-assisted, classification criteria can be codified to allow for more consistent application, potentially reducing subjectivity error.
- Land cover changes and / or changes in habitat quality were detected by several of the change detection techniques employed. Results of the study demonstrate that important information about habitat condition and change in condition can be derived from ADAR imagery.

Conclusions:

- Results of our comparison of methods indicate that third-party geometric processing of ADAR image data is not currently cost-effective. This is due in part to the rapidly evolving and unperfected state of commercially available image processing technologies.
- Comparison of relative benefits of using ADAR technology rather than conventional mapping methods indicated that ADAR has distinct advantages over conventional techniques, which inevitably translates to greater cost-effectiveness.

Recommendations:

Results of this study indicate at least three important areas for further research.

- Apply image processing and classification techniques to other habitat types, such as conifer forest, and other woodland and upland plant communities.
- Establish a long-term change detection study to further define and refine ADAR's valuable change detection capabilities.
- Identify ADAR image attributes that correspond to habitat quality.

All three of these research topics would significantly advance ADAR's utility in areas that, based on results of this study, ADAR technology offers the most promise for realizing its cost-effective potential.

Abstract

Southern California Edison undertook research with California Energy Commission funds as part of the Commission's PIER (Public Interest Energy Research) research program.

This research, entitled Habitat and Species Protection, involved three main components that seek to minimize the impacts on habitats and species from the siting operation and maintenance of utility transmission and distribution systems. The three main components are: 1) Raptor mortality studies in southern California; 2) Multiple species habitat protection; and, 3) California habitat evaluation.

The research on raptor mortality examined the interactions of raptors and power lines within two raptor concentration areas within SCE's service territory. Similar techniques were used in both study areas to examine the level of raptor mortality in each area. This research demonstrated that mortality does occur, but at very low levels. In the San Jacinto Valley study area, a total of 7 dead raptors were found, only two of which could be attributed to electrocution. In the Owens Valley study area, 11 raptors were found, 6 of which were known or suspected electrocutions. These data yield a mortality rate of 0.00010 electrocutions per month per surveyed pole in the San Jacinto Valley, and 0.00048 electrocutions per month per surveyed pole in the Owens Valley. These are extremely low numbers, especially when compared to what other western utilities have experienced.

The multiple species habitat conservation protection (MSHCP) research component consisted of a number of tasks designed to enhance species conservation by promoting the use of multiple species habitat conservation planning, education and management of multiple species preserves. These tasks consisted of holding a workshop on MSHCP planning in order to facilitate the process; furthering the data base on the California gnatcatcher, a primary species for protection of the coastal sage scrub community in southern California; ecological risk modeling of the desert tortoise; using the metapopulation tools developed for the desert tortoise and the gnatcatcher as an educational tool by providing access to RAMAS® GIS 3.0 software; and an examination of correspondence between the World Conservation Union's (IUCN) and U.S. Fish and Wildlife Service's classification of species at risk.. This research has resulted in research reports designed to enhance development of multiple habitat preserves, aid in their management and will assist in the management of existing and future facilities which traverse many of the current and proposed multiple species habitat preserves.

The California habitat evaluation research component develops operational protocols to characterize and monitor critical habitats in California using high resolution airborne multi-spectral imagery using a system called Advanced Digital Airborne Registration (ADAR). This research will support the development and management of multiple species habitat preserves by closely monitoring small changes in measured environmental variables to detect how effective certain management prescriptions are performing and how the habitat is responding to biotic and abiotic variables. This research has established the value of ADAR technology to support management of preserves and species in southern California.

1.0 Introduction

1.1 Background to California Energy Commission Public Interest Energy Research Program

The Public Interest Energy Research (PIER) Program was developed by the California Energy Commission (CEC) in response to Assembly Bill (AB) 1890, which provided authority for a fundamental restructuring of California's electric services industry. As a result of the implementation of AB 1890, approximately $61.8 million is transferred from the California Public Utilities Commission (CPUC) annually to the CEC to administer specific Research Design and Development projects.

The overall mission of the PIER program is to "improve the quality of life for California citizens by providing environmentally sound, safe, reliable, and affordable energy services and products." In 1997, Senate Bill 90 was enacted into law and included five subject areas for expenditure of funds under the PIER program. One of these five criteria is "Energy Related Environmental Enhancement" under which Southern California Edison's (SCE's) Habitat and Species Protection Project was funded.

Three specific research tasks were identified in as part of the Habitat and Species Protection research program. These three research tasks included Raptor Protection Research, Multiple Species Habitat Conservation Planning (MSHCP), and California Habitat Evaluation. Each of these research tasks is described in more detail later in this section and in other sections of this report.

1.2 SCE's Research Needs - A Historical Perspective

SCE operates and maintains a complex array of distribution and transmission line facilities in central and southern California. Within this 50,000 square mile service territory, there are more than 100 rare, threatened, or endangered species, and several hundred species of concern. Issues involving the effects and potential effects of electric facilities on sensitive species and their habitat are currently being addressed by SCE. For example, SCE has maintained a very active endangered species protection program for over 10 years. This program, SCE's Endangered Species Alert Program (ESAP) is an award-winning program designed to minimize and/or avoid impacts to legally protected species and other sensitive biological resources.

The main component of ESAP is a manual that contains information on all listed species within SCE's service territory. SCE planners and maintenance people review this manual prior to performing any ground disturbing activity to determine if any legally protected species potentially occur in the area. If it is determined that they do, then an SCE biologist is called in to review the proposed activity and to find methods for accomplishing the necessary work without impacting the sensitive resource. This program has worked well to minimize or avoid SCE's impacts on sensitive biological resources and thereby maintain SCE's compliance with state and federal law. The ESAP manual is in its 3rd edition, and has recently been made available on SCE's intranet, so anyone in SCE can access the manual via SCE's Environmental Affairs home page.

Other programs that SCE has undertaken in support of SCE's endangered species protection program include:

- Preparing special maps showing the distribution of listed species in relation to our power lines
- Financially supporting Multiple Species Habitat Conservation Planning in Riverside County
- Researching the desert tortoise and other listed or sensitive species (island fox, bald eagle, California gnatcatcher, etc.)

Most recently, the SCE developed and implemented a program called Archaeological and Biological Resource Application (ABRA), which allows users to view a USGS quadrangle map, with SCE transmission lines displayed. The user can identify an area where ground-disturbing activities are planned by clicking on a portion of the map. The ABRA program will then identify if there are biological or archaeological sensitivities in the area by displaying a dialogue box. If sensitivities are known or expected to occur in the area, it will identify whether the sensitivity is biological and / or archaeological in nature. By clicking on the sensitivity category, a new dialogue box will appear identifying the exact nature of the sensitivity, and provide information on avoiding the sensitivity or provide direction on contacting Environmental Affairs. If the sensitivity is biological in nature, it will provide a list of species or natural communities known or expected to occur at the given location. If the species is a listed species, one can click on the species name and it will open the corresponding page from SCE's ESAP manual, providing the reader with the most current information available about the subject species.

SCE facilities occur in regions supporting raptor concentrations that vary throughout the year. During winter, raptors concentrate in portions of SCE's service territory, specifically the San Jacinto Valley in Riverside County and the Owens Valley in Inyo County. In these mostly treeless environments, raptors will utilize SCE's power line poles and towers for perching and roosting. In many cases, raptors also nest on these facilities. High use of SCE power lines can significantly increase the potential for electrocution-caused mortality.

SCE has maintained a Raptor Protection Program since 1986. This program consists of educating field personnel on procedures to follow in dealing with raptor mortality and how to protect active nests. The program works on the "preferred pole" concept. That is, raptors are known to display preferences in which poles they perch on. Their selection is often based on a variety of factors, including prey availability, habitat diversity, topography, prevailing wind direction, etc. During the fall of 1997, SCE conducted research to determine whether a significant raptor electrocution problem exists in the San Jacinto Valley. After extensive field work, no raptor mortality or power outages were recorded due to electrocutions. The results of the 1997 research indicated that the rate of raptor mortality from electrocution is significantly lower than previously reported by the California Department of Fish and Game. The Raptor Protection Research component of this document is a continuation of work that SCE initiated in 1997. In addition to continuing and expanding on this work, similar research was conducted in the northern Owens Valley region.

1.3 SCE's Goals and Objectives

The Habitat and Species Protection Program includes three components that seek to minimize the impact on habitats and species from the siting, operation, and maintenance of utility transmission and distribution systems. These three components are:

- Raptor Protection Research
- Multiple Species Habitat Conservation
- California Habitat Evaluation

Raptor Protection Research

The Raptor Protection Research component is designed to quantify the severity of raptor electrocutions occurring on power poles and/or towers. It documents actual levels of raptor use and mortality occurring on utility power line systems and provides recommendations to reduce this mortality using methods that are both cost-effective and likely to improve system reliability. These methods may be applied to power line systems not only within SCE's service territory, but throughout California to reduce mortality to raptors statewide.

Raptor mortality due to interactions with powerlines is well documented in scientific literature and in utility industry publications. Raptors are protected pursuant to several state and federal regulations. These include the state and federal Endangered Species Acts, the Bald Eagle Protection Act, California Department of Fish and Game Code and the federal Migratory Bird Treaty Act. Direct and indirect application of various elements of these laws require SCE to provide prudent management measures to minimize and avoid impacts to these protected species. By combining data and findings from the Owens Valley and the San Jacinto Valley, SCE is much closer to a system-wide pro-active approach and solutions to minimizing raptor electrocutions and overall compliance with agency regulations.

Multiple Species Habitat Conservation Plan (MSHCP)

The MSHCP research task directly addresses land use issues as they relate to sensitive species. Through research designed to facilitate the development of multiple species habitat reserves, this component will aid in providing protection for endangered species through an ecosystem approach at lower cost and with less conflict than the traditional species-by-species approach. This information will be invaluable both in the siting of new facilities and the management of existing facilities and rights-of-way which traverse multiple species habitat preserves.

California Habitat Evaluation

The California Habitat Evaluation component develops operational protocols to characterize and monitor critical habitats in California using high-resolution airborne multi-spectral imagery obtained using a system called Advanced Digital Airborne Registration (ADAR). This research supported the establishment of multiple species reserves with the highest habitat values, and will aid in more timely management responses to changes in the environment.

1.4 Report Organization

This report is organized first with some introductory material (Sections 1 and 2), providing some background on the research topic, and SCE's interest, history, and involvement with these issues. Goals and objectives of the overall research program and individual research tasks are also identified.

Following these introductory sections, a summary of each research task and research component of each task is provided in Section 3. These summaries represent a distillation of the individual consultant reports that are attached as appendices to this report.

Section 4 provides an overview of the research performed, summarizing the information learned from this overall research project and integrates all individual research tasks and research components. Section 5 lists references used in preparing this material.

Individual consultant reports are bound separately and attached as appendices to this report.

2.0 Approach

2.1 PIER Funding

SCE addresses important research needs in its "Habitat and Species Protection Program," one of the projects funded under contract number 500-97-012 issued on December 28, 1997. The Program consists of three components: Raptor Protection Research, Multiple Species Habitat Conservation, and California Habitat Evaluation. Although some of the research conducted for this Program is habitat- or species-specific within SCE's service territory, the methodologies and databases developed have regional and statewide applications.

2.2 SCE's Management and Quality Control

SCE was the primary investigator for this research, although most of the work was performed by qualified consultants working under SCE's guidance. In addition to laying out the work scope in concert with the individual consultants, SCE made adjustments as necessary to ensure that work was directed towards providing greatest benefit to the environment and the electric utility consumer. SCE has worked closely with the individual consultants to ensure that the final reports reflect this commitment to the environment and to the electric ratepayers of California.

In addition to overall direction in establishing the scope and direction of the research project, SCE oversaw the ongoing work, and worked directly with individual consultants to answer questions and provide guidance and direction. .

2.3 Selection of Contractors (Consultants)

A team of consultants was already working on SCE research projects specifically related to this research. Hence, it made sense to maintain the same consultants for the California Energy Commission PIER funded research in order to minimize costs and maximize use of previously gathered information. Consultants originally selected for this work, prior to PIER funding, were preeminently qualified to undertake this research. A discussion of the qualifications for each of the consultants follows:

- **BioReource Consultants** - This organization is headed by Carl Thelander. Mr. Thelander has over 20 years experience providing biological consulting services throughout the western United States, especially to major electric utilities in California. Carl has specific expertise with raptors, endangered species, and ecological systems modeling. Because of his vast experience as a biological consultant, Carl also has a vast network of contacts that are involved in protecting and managing biological resource issues here in California. This experience made Carl Thelander and BioResource Consultants ideal candidates to manage the Raptor Protection Research task, and the MSHCP Workshop component of the MSHCP research task. For this latter task, Carl solicited the assistance of Dr. Mike Morrison, Adjunct Professor at California State University at Sacramento. Dr. Morrison's expertise is experimental design, HCP development, and statistical analysis. Dr. Morrison was the principal coordinator and manager of the MSHCP Workshop held at SCE offices in March, 1999. Dr. Morrison has also been involved in the Raptor Protection Research task, helping establish sampling design and statistical analysis of data.

- **Applied Biomathematics -** Applied Biomathematics has been under contract to SCE and the Electric Power Research Institute (EPRI) for a number of years. Their expertise is in mathematical modeling of populations and population viability analysis (PVA). Key members of their staff that have participated in this research have been Dr. Lev Ginsburg, Dr. Resit Akçakaya, and Dr. Karen Root. Applied Biomathematics has developed the well-known and widely distributed RAMAS® software, which is principally a program for performing PVAs of various species. Dr. Karen Root was responsible for *the Desert Tortoise Metapopulation Dynamics* and *The Metapopulation Model as an Educational Tool: Providing Internet Access to RAMAS®-GIS Software* research components of the MSHCP research task. Dr. Resit Akçakaya was primarily responsible for the *Conservation and Management of Coastal Sage Scrub* and the *Correspondence Between IUCN and USFWS Classifications for Threatened Species* research components of the MSHCP research task.
- **Dr. Peter Bowler -** Dr. Bowler is a professor at the University of California, Irvine. His expertise is in habitat dynamics and restoration and coastal sage scrub ecosystems. Dr. Bowler has been involved in long-range research on the California gnatcatcher, including several years for SCE. Dr. Bowler was responsible for the Monitoring and Management-related Research on California Gnatcatcher and Cactus Wren Subpopulations in the San Joaquin Hills and Palos Verdes. Dr. Bowler collaborated on the research with Dr. Jonathan Atwood, considered by many to be the preeminent expert on the California gnatcatcher.
- **Ed Almanza, SuperPark Project -** Ed Almanza has been involved in ADAR (Airborne Data Acquisition and Registration) for a number of years, pioneering the development and implementation of this relatively new data acquisition system. Mr. Almanza has also worked for a number of years on coastal sage scrub and NCCP issues, particularly in Orange County.

2.4 Schedule of Work

Work on the individual research tasks was initiated in 1998. For that work involving field studies, work was performed at the appropriate time of the year to ensure adequate data collection.

2.5 Preparation of Deliverables

Consultants prepared reports of their findings as work progressed. These reports can be found as appendices to this document.

2.6 Integration by SCE

Overall direction and guidance on the Habitat and Species Protection Research Program was provided by SCE. All of these research tasks comprising this research program have in common a relationship to power line siting and operation and maintenance activities, and the effect that these facilities have on sensitive biological resources that can be found within the right-of-ways for these facilities. Additionally, the research tasks and components have the ability to extend beyond the electric utility rights-of-ways, and have potential application and benefit for others in California.

3.0 Research Results

3.1 Raptor Protection Research

3.1.1 Assessing Power Line Use and Electrocutions by Raptors

3.1.1.1 Background

SCE operates electrical generation, transmission, and distribution facilities in a diverse service area that extends from rural / undeveloped Fresno / Mono counties in the Sierra Nevada to urban Los Angeles / Orange counties on the south, and to Arizona and Nevada in the east. A majority of this 50,000-square-mile service area is comprised of rural agriculture lands or natural vegetation. These areas support a variety of wildlife species, including numerous raptors. Raptors are defined as birds of prey, such as hawks and owls.

Utility power poles attract raptors for numerous reasons (Bevanger 1994). Primarily, they provide perches from which nocturnal and diurnal species can hunt, feed, and sometimes nest. While raptors benefit from the distribution and number of the power poles, these artificial perches have hazards in the form of energized components or hardware. . When raptors make contact with these energized components, they are sometimes killed or injured by electrocution (Bensen 1981; Kochert and Olendorff 1999; Olendorff et al. 1981; Williams and Colson 1989; Miller et al. 1975). Williams and Colson (1989) identify 17 species of raptors that have been electrocuted in the western United States.

Raptor protection measures are often incorporated into the permitting and licensing requirements placed upon the utility industry for new power line projects. In addition, SCE has implemented its own Raptor Protection Program. This program is designed to identify problem areas or poles so that appropriate modifications can be made, and to monitor raptor electrocutions system-wide. Poles associated with electrocution events, or suspected of causing them, are modified to make them safer and to discourage raptors from perching on them.

The causes of raptor electrocution are well documented (APLIC 1996). The size of the bird is by far the most crucial factor in certain species' being more prone to electrocutions. Larger birds are more likely to span conductors with outstretched wings or other body parts. Most electrocution events occur on distribution lines rather than high-voltage transmission lines (Olendorff et al. 1981). The frequency of electrocutions is highest in areas where raptors congregate in response to prey availability.

3.1.1.2 Objectives

In the SCE service area, several regions support particularly large concentrations of raptors, especially during the fall and winter months. The purpose of this research project was to characterize and quantify raptor use in two of these raptor concentration areas. Concurrent with the raptor use surveys, raptor fatality searches were conducted under the same power poles. By combining the results of these surveys, the relative level of risk to raptors associated with perching on power poles could be determined in these two regions, and factors influencing raptor perch selection could be assessed.

One additional (non-survey) study objective was to evaluate the reporting procedures used in SCE's Raptor Protection Program. To do this, the raptor fatalities encountered in the field were compared with data reported within SCE's computer database of power outages and causes. Also, interviews were conducted with maintenance personnel responsible for reporting and investigating raptor electrocutions and other system outages in each of the study areas. The goal of this latter effort was to take SCE's already effective Raptor Protection Program and improve it so that it would be more effective in providing protection to raptors.

3.1.1.3 Methods

Study Areas

In the San Jacinto Valley, Riverside County, 35.1 miles of roadside survey routes were established. A total of 1,802 power poles were represented in these surveys. In the Owens Valley, Inyo County, 72.8 miles of roadside survey routes were established. A total of 1,679 power poles were represented.

In both study areas, survey routes were selected for their proximity and access to distribution power lines that traverse the areas. This included roads ranging from highways to dirt maintenance roads, or segments where walking was required. The length of the routes was primarily determined by the number of poles that could be thoroughly surveyed on foot for dead raptors no less than twice per month.

Survey Methodology

Initially, each study area was visited to establish the survey routes and define the pole locations to be included in the surveys. Once the routes were established, the same poles were surveyed during each sampling event. All poles included in the surveys were inventoried and characterized by type (approximately 25 configurations represented) based on their line and insulator installations. Each type was assigned an alpha-numeric code for use on data collection forms.

The survey routes were subdivided into numerous segments and assigned numeric codes that coincided with road intersections, changes in power line direction, or some other obvious landmark or physical feature. Within each segment, each power pole was assigned a unique identification number. This segmentation helped maintain accuracy in assigning pole numbers during data entry and in navigating the complex survey route.

While the approach to the research in each of the two study areas was generally the same, the field effort applied in the San Jacinto Valley was more intensive than that applied in the Owens Valley. The San Jacinto Valley research was designed and underway by October 1997. The first survey period was from October 1997 through March 1998. The second survey period was from November 1998 through March 1999. The Owens Valley research was initiated by BioResource Consultants from February-April, 1998. SCE funded the second survey period, from November, 1998 to March 1999.

Roadside raptor counts are a widely used method of determining species occurrence and relative abundance. The data collection was limited to raptors perched on power poles. Flying raptors were not included in the counts. In the first survey period in each study area, intensive roadside raptor counts were conducted to quantify raptor use of power poles. These surveys were conducted independently from the fatality searches.

In the second survey period in each study area, intensive roadside raptor counts were not conducted. Instead, only those raptors observed on power poles were recorded while conducting continuing fatality searches. A priority was placed on surveying for electrocuted raptors, since this was the most time-consuming task, and the primary focus of the research effort. . Therefore, the raptor-power pole use results for the two samples in each study area were not meant to be directly comparable.

Fatality searches required a combination of driving slowly and walking along the survey routes to visit each power pole. The raptor fatality survey methods used in all study periods and in both study areas remained comparable throughout the study.

Electrocuted raptors are typically found at the base of power poles. They die immediately and fall to the ground. Therefore, a minimum radius of five meters around each pole was intensively searched for the presence / absence of dead birds. In most areas, a much larger area was easily surveyed, since vegetation was usually sparse or non-existent.

When evidence of a bird was present, a standardized set of data entries was recorded onto a field form. A field inspection was conducted to determine the cause of death. When whole carcasses were found, they were taken to a qualified veterinarian for necropsy.

Raptor Mortality Surveys

The fieldwork was scheduled to ensure that every power pole was surveyed for dead raptors twice per month. The San Jacinto Valley routes were surveyed twice per month in October 1997 through February 1998. One survey was completed in March 1998. The Owens Valley routes were surveyed twice per month in February and March 1998 and once in April 1998. These routes were surveyed twice per month in November 1998- February 1999. A single (final) survey was completed in March 1999.

Raptor Use Surveys

Each raptor use survey consisted of one (sometimes two) observer(s) driving along the predetermined route(s). . Generally, roads were traveled at a safe rate of speed suitable for observing and identifying to species any raptor perched on a power pole. Every raptor (except American kestrels and common ravens) observed perching on a power pole was recorded. The pace of the survey was dictated by the frequency of raptors along the route. The observers stopped when necessary to ensure a complete census of every pole. As needed, a spotting scope was used to make accurate species identifications.

All surveys began in the morning, usually by 7:30, and ended before 11:00 a.m. to maximize the number of observations of perched raptors. Starting points along the survey routes varied randomly. The sampling schedule was maintained regardless of weather conditions.

Each raptor observed perching was recorded as a single event. All data were recorded in the field using standardized forms. These data were then transferred to electronic databases using Microsoft Excel software. The raptor use form included data fields for date, route, observation number (sequential per day), species observed, survey segment, pole number, pole type, location on pole, predominant habitat type adjacent to the pole, weather, wind, and other comments.

3.1.1.4 Outcomes

In the San Jacinto study area, from October 6, 1998 to March 15, 1999, 92 raptor use surveys were completed: 56 on the east route and 36 on the south route. The second set of surveys occurred between November 1, 1998 and March 15, 1999. These surveys were conducted incidental to the fatality searches, which progressed at a rate of two complete surveys per route per month.

In the Owens Valley study area, from February 1, 1998 to April 16, 1998, 36 raptor use surveys were conducted. The study area was divided into four routes (seven at Chalfant, 15 at Laws, 10 at Round Valley, and four at Mill Pond. The second set of surveys was conducted incidental to fatality searches conducted between November 1, 1998 and March 15, 1999. No record was kept of incidental raptor observations during the initial November surveys.

Raptor Fatalities

Twelve raptor fatalities were found in the Owens Valley study area. Of these, it is believed that as many as seven may have died as a result of shooting. All of these occurred in the Five Bridges area north of Bishop. Fatality event numbers 1 through 5 and 10 through 12 were all killed during the survey period. Fatality event numbers 6 through 9 appeared to be old kills when they were discovered. The cause of death could not be determined, and according to a CDFG biologist, the area has had problems with raptor shootings. Therefore, four of the 12 fatality events were excluded from analysis of risk due to electrocution during the period of the surveys.

Seven raptor fatalities were found in the San Jacinto Valley study area. Fatality event numbers 1 and 2 were old carcasses of birds that died before the surveys began. Fatality event numbers 3 and 4 were unusual in that both birds were found together lying on their backs. A necropsy revealed no known cause of death. There was no evidence of electrocution. Fatality event number 5 had scorched wing feathers and was therefore considered likely to have been electrocuted. Fatality event number 6 was found fresh but the necropsy revealed no known cause of death. Fatality event number 7 was an old carcass (bones only) that was uncovered by recent rains. Therefore, only one verified electrocution occurred in the study area during the course of the surveys. It is likely, however, that some of the others found were electrocuted prior to the surveys.

Raptor Use of Power Poles

A total of 2,902 raptors were observed during the raptor perching surveys in the San Jacinto Valley and Owens Valley study areas. Red-tailed hawks were the most commonly observed species during both the surveys.

Raptor Electrocution Risk

The risk of death due to electrocution was very low in both of the study areas surveyed. Of the 12 fatalities found in the Owens Valley study area, four were excluded from analysis due to the age of the carcass when found. Therefore, for purposes of this analysis, it was assumed that as many as eight kills occurred during seven-month period of the surveys. Based on this assumption, the fatality rate was approximately 1.14 electrocution events per month during the course of the surveys.

In the San Jacinto Valley study area, it was assumed that three of the seven fatalities found occurred prior to the surveys. While it is possible that the remaining four fatalities were associated with electrocutions, evidence was not conclusive and these fatalities were not deemed to be electrocutions. Based on this assumption, the fatality rate was approximately 0.348 electrocution events per month during the 11.5-month course of the surveys.

To compare these two fatality rates, the fatality rate was indexed to the number of poles included in each survey route. This converts the fatality rate index for the San Jacinto Valley study area (n= 1,802 poles) to 0.00019 kills per month per pole surveyed. The comparable value for the Owens Valley study area is 0.00068. This would seem to indicate that the frequency of raptor electrocutions is 3.5 times greater in the Owens Valley study area than in the San Jacinto study area.

The risk of electrocution in the San Jacinto Valley region is extremely low when compared to that of the Owens Valley. For example, the fatality rate was lowest in the study area that supported the highest use by red-tailed hawks. The power pole use surveys indicate that red-tailed hawks perch approximately twice as frequently in the San Jacinto Valley as in the Owens Valley, yet their fatality rate is much higher in the latter study area. This is also true for golden eagles.

3.1.1.5 Conclusions

In general, there was a high degree of cooperation by SCE field personnel when it came to reporting raptor electrocutions. The procedures have been widely circulated throughout the company. Training and communications have been effective in getting the program implemented. The Raptor Protection Program has been in place for over a decade. It is standard operating procedure to report raptor electrocutions to SCE's Office of Environmental Affairs.

It appears that primarily only those raptors that cause a circuit outage get reported. The field surveys confirmed that not all raptors that are electrocuted actually break the circuit and come to the attention of the maintenance personnel. This results in a general under reporting of the true extent of raptor electrocutions, both in the study areas surveyed and probably throughout the service area. There may be ways to set the sensitivity of the circuit breakers to be more responsive; however, there is a reluctance to do this because it may result in more frequent service interruptions.

3.1.1.6 Recommendations

During the course of the project, an electronic database was created of the historical records of raptor electrocutions on file with SCE's Office of Environmental Affairs. This database should be kept current with new fatalities entered into the database as they occur. This will ensure thorough monitoring of the extent of electrocutions and the general distribution of the events. Using this database, priority areas needing modification to prevent perching or electrocution can be identified.

Raptor use of power poles cannot be predicted reliably by simply evaluating a pole's particular configuration, or its location on the landscape. Predicting electrocutions is even more difficult. Additional environmental factors unrelated to the physical characteristics of the poles almost certainly dictate whether or not a particular pole is used by raptors. These factors may include habitat conditions, topographic features, prey availability, and prey vulnerability specific to each raptor species and within the hunting radius of the pole. Also, remoteness from disturbance by people and vehicles may play an important role in raptor pole selection.

Future efforts to minimize raptor electrocutions should focus on the development of predictive models that: (1) identify regions, lines, or specific poles with a high probability of raptor use by vulnerable species, and (2) identify pole line configurations that have documented raptor electrocutions associated with them.

Once these models are developed and tested, utilities can inventory their distribution systems for the frequency of occurrence of individual poles assigned the highest ranking as potential problem poles. As resources permit, modifications and perch deterrents can be installed to further minimize the likelihood of future electrocutions. Using methods similar to those applied in this research will yield an index of raptor electrocutions that can be compared from region to region. Progress toward reducing electrocutions could be examined using pre-treatment versus post-treatment fatality survey data.

SCE's Raptor Protection Program is a useful tool for monitoring raptor electrocutions, identifying areas or individual poles needing modifications to reduce electrocutions, and educating SCE field personnel on the proper procedures to follow when a raptor electrocution occurs. It appears that the full extent of raptor electrocutions at SCE facilities may be under-reported. Steps to improve this situation need to be developed.

For more information on this Research Task Component see Appendix I.

3.2 Multiple Species Habitat Conservation Planning

3.2.1 MSHCP Workshop and Proceedings

3.2.1.1 Background

For years, the development of Multiple Species Habitat Conservation Plans (MSHCPs, or HCPs) has been identified as a preferred mechanism for dealing with the innumerable conflicts between endangered species and sustainable economic development. With over 500 state and federally-listed species within California, the potential for conflict between these species and proposed economic development, even ongoing activities for infrastructure maintenance, is very high. One of the ways that SCE believes that this conflict can be reduced is to have MSHCPs in place that provide a mechanism for protecting multiple species and their associated habitats, but also allow for development to proceed in a controlled and predictable pattern. This is a preferred approach over dealing with endangered species conflicts on a project-by-project or individual species basis.

3.2.1.2 Objectives

The goal of the MSHCP workshop was to facilitate the development of MSHCPs in California. SCE's goal in this workshop was to bring together some of the top experts involved in creating, planning, and managing MSHCPs, to allow for an exchange of ideas and thoughts. In this way, others involved in developing MSHCPs could benefit from the collective knowledge and experience of the participants.

3.2.1.3 Workshop Attendees

The multiple-species planning workshop was held from March 3 to 5, 1999 at the SCE offices in Rosemead. Attendees for all or part of the workshop included Dan Pearson, Jim Young, Bill Ostrander, Kim Gould, Kathleen West, Janet Baas, Cristi Tomlin, and Mike Hertel (SCE), Shawn Smallwood (UC Davis), Mike Morrison and Patrick Foley (California State University, Sacramento), Resit Akcakaya (Applied Mathematics), Steve Lacy (Ogden Environmental), John McCaull (National Audubon Society), John Bradley and Catherine McCalvin (USFWS), Tom Scott and Rick Redak (UC Riverside), Brian Loew (Riverside County Habitat Conseration Agency), Peter Bowler (UC Irvine), Robert Asher and Robert Copper (San Diego County), David Moser (McCutheon, Doyle, Brown and Enerson), Trish Smith (The Nature Conservancy) and Mark Sazaki (CEC).

3.2.1.4 Workshop Summary and Synthesis of Recommendations

Initial Expectations/Issues

Workshop participants began by listing key issues that were hindering successful completion and implementation of MSHCPs. Throughout the workshop, the group returned to this initial list to determine if these issues were being covered, and to supplement the list as new issues arose. The initial list was not meant to provide a group assessment, but rather to simply get issues on the table for discussion. The issues were:

- Avoidance of a "cookbook" approach to designing HCPs.
- The importance of developing standard applications of science to the HCP process.
- The relationship between the HCP enabling legislation (i.e., Section 10 of the Endangered Species Act) and the application of science to the HCP process.
- Incorporation of a rigorous Peer review process.
- Applications of ecological and population models to HCP development.
- The perspective of management and regulatory agencies into practical HCP development.
- In general, what steps can be taken to improve the HCP process?
- Methods to improve communication among all parties (stakeholders) involved in developing and approving a permit application, including pubic education and comment.
- The quality of the data that should go into developing an HCP, and how to deal with scientific uncertainty.
- What role do mitigation banks have in HCPs?

- Reserve design (including buffer areas), and the related issue of reserve management.
- The use of monetary incentives for improving HCP design and implementation, and in changing existing HCPs in light of new information.

Additional Issues

At the end of the first day of the workshop, participants reviewed the above initial issues list, and added the following items for further consideration:

- Should plans be written from the “bottom-up”, whereby science drives the planning process; or from the “top-down”, whereby major planning issues are first identified and then science is brought to bear on key issues In short, when should science enter the process?
- The role of HCPs as repositories for plants and animals that are being eliminated elsewhere through development.
- Public availability of data for use in development of HCPs.
- What is the likely direction for the use of HCPs into the future?
- How can an approved HCP be improved in light of new information? This topic relates to the issue of adaptive management.
- How can new research initiatives (to improve data quantity and quality) be incorporated into an HCP?
- How is “success” of an HCP measured?
- What is the proper role for HCPs to contribute to (Endangered Species) Recovery Plans?
- The problems associated with the lack of available expertise in developing and then reviewing a plan.

Conclusions/Guides for Improving HCPs

At the conclusion of the workshop, participants again reviewed their initial and modified lists of issues and expectations, and developed the following set of conclusions and recommendations for improving the HCP process.

- Revise the HCP handbook. There was general consensus that the current Handbook was too vague and did not provide adequate guidance on most aspects of HCP development. Sections that needed addition or strengthening included:
  - How to access and incorporate stakeholder input throughout the planning process.
  - Guidance on how U.S. Fish and Wildlife Service (FWS) personnel could be incorporated into all phases of a plan’s development.
  - A clear discussion of adaptive management that cross-walked with current scientific literature on the topic.
  - Guidance on linking plan goals to measures of project success, and how success could be determined through post-implementation monitoring (e.g., study design, appropriate statistical analyses).
- A statement from FWS needs to be made regarding the use of population viability analyses (PVA) in plan development and evaluation; what are the data requirements

and allowable uses of a PVA? The goals for population modeling need to be clearly stated.

- The uncertainty associated with each major data set and decision in a plan needs to be clearly elucidated. This will allow plan proponents to have a better understanding of what they are proposing, and will allow all stakeholders to gain a better sense of the strengths and weaknesses of the data that went into a plan alternative.
- The standards for acceptable data (in plan development) need to be clarified. A general consensus emerged that "best available" data is too vague, because the "best" might not necessarily be reliable. Thus, the quality of each data set used in plan development must be clearly discussed.
- Standards should be established for how all material used to build an HCP are referenced. Although there was no consensus on how this should be reported to the public, it was agreed that a clear link between each decision within an HCP and the source of material used to arrive at that decision be established. For example, a decision could be based on anything from expert opinion to peer-reviewed literature. Identifying this link is essential for informed review of any plan.
- Independent peer review should be incorporated into each major stage of the planning process. This process would identify weaknesses in all data sets and preliminary decisions, and help reduce overall approval time of a plan.
- It was agreed that project management, including especially a detailed front-end scoping of a plan, be initiated by the FWS. This would help to more clearly identify major issues that need to be addressed early in the process.
- The issue of "species-based" vs. "ecosystem-based" plans needs clarification. Although there was consensus that plans should consider multiple species, it is important that all parties to a plan realize that "umbrella" or "indicator" species approaches seldom adequately protect all species covered under an HCP. This is because each species has unique habitat and niche requirements. Thus, an "ecosystem" approach is best understood as a "multiple-species" approach.
- Greater emphasis should be made on incorporating all stakeholders, including agencies, at all stages of the planning process. Greater attempts should be made to gather as much public input as possible throughout the process.
- It was agreed that the FWS has not been adequately funded by Congress to manage the HCP process. Thus, new funding mechanisms need to be developed to increase the number of personnel available. A recommended option was for permit applicants to financially support FWS and other agencies for personnel for the duration of a planning process. For example, there was agreement that an agency person should be assigned to assist with project management, and that the permit applicant should financially support an agreed-upon portion of the person's time. This would have the added benefit of increasing stakeholder involvement.
- People possessing a wider range of skills need to be incorporated into the planning process. Specific expertise areas needed include:
  - local land use planning issues and regulations
  - project management

  - hydrology
  - conservation biology, wildlife biology, and ecology
  - knowledge of best land management practices (BMPs)
  - engineering
  - adaptive management
  - study design (including impact assessment) and monitoring
  - preserve management
- The specific goals of each plan over time must be stated, as well as specific criteria for measuring success of the plan.
- There appears to be general confusion on the role that an HCP can play in recovery of a species. The law specifically forbids an HCP to substitute for a Recovery Plan. However, HCPs are expected to contribute to species recovery. The FWS needs to better clarify the role of an HCP in recovering a species, especially given that HCPs usually permit take of covered species.
- All stakeholders need a basic understanding of project financing. This would help people understand what a permit applicant could and could not accomplish, with regard to mitigation and other plan requirements.
- There is often inadequate time available to fully design and implement an adaptive management approach into the HCP plan. As such, with the caveat that adaptive management should be incorporated early-on following plan approval, it was suggested that BMPs could be used to establish HCP preserves. Then, as data are gathered, a more formal adaptive management strategy could be implemented. Of course, the requirement for incorporation of such an adaptive management plan would need to be explicitly stated and designed into permit approval. However, BMPs allow evaluation of a proposed and developing preserve and the initial actions recommended for improvement of the habitat of specific covered species. There are many such models available (e.g., state forest practice rules), and efforts could be expended on synthesizing available data and expert opinion into developing BMPs for covered species. In addition, BMPs that address principles of reserve design and management can be gathered.
- The admittedly evolving nature of the HCP program administration by the FWS allows challenges of interpretation of the rules by permit applicants. The FWS needs to expend the resources necessary to establish firm guidance for its various offices and personnel throughout the United States.
- There needs to be clear guidance on what constitutes acceptable mitigation from the standpoint of endangered species policy. A helpful addition to HCP guidance by the FWS would be examples of recommended strategies for mitigating project impacts. Guidance involving major concepts of reserve design, the use of buffer areas and corridors, monitoring standards, etc. should be established. All guidance should be directly keyed to the relevant scientific literature.
- There was consensus that each HCP should contribute to the overall understanding of ecological processes driving the HCP concept. That is, projects should be planned so

that successes and failures in strategy and implementation can be documented and future projects can benefit from the knowledge. For example, if corridors are implemented as mitigation for fragmenting a preserve, then research should be incorporated into the monitoring phase of the project so the success of the corridor can be determined. This process should also instill confidence in all stakeholders regarding the seriousness of the FWS and permit applicant in devising a plan that promotes species survival. Such research-monitoring activities will be most successful if packaged with a workable adaptive management strategy that includes a funding vehicle for allowing future changes in the HCP.

- Each area and the species within it have their own unique distributions; HCPs should not become museum pieces of tiny fragments, rather they should cohesively act as protection measures throughout a species distribution, complementing but not replacing Recovery Plans.
- Lands to be developed ("taken") could be viewed as research tools, so that certain ecological experiments could be performed prior to habitat destruction. Additionally, consideration should be given to removing (transplanting) selected animals and plants if there is concern over loss of genetic diversity.

Workshop Presentations

Formal presentations were given during the workshop to provide background information, and serve as a catalyst for discussion. The workshop papers were divided into two major sections: Regulatory Issues and HCP Planning; and Conservation Biology and HCP Development. The first deals primarily with the legal foundation of the HCP process, perspectives from the standpoint of an environmental group and local and county governments, and weaknesses between the HCP Handbook and implementation of actual HCPs. The second section covers many of the scientific foundations of planning for multiple species preserves, including fundamental concepts of conservation biology, modeling the extinction process, landscape planning and wildlife habitat, and the lack of knowledge regarding the status of arthropods. Abstracts from the papers that were presented are located in Appendix III.

3.2.1.4 Deliverables

Dr. Michael Morrison and Dr. Shawn Smallwood, the workshop organizers, identified two sources of publication for the results of this workshop. A summary will be published in an upcoming book on Mediterranean ecosystems being edited and written by Dr. Peter Bowler. In addition, the papers presented at the workshop will be published in a special supplemental edition of Environmental Management.

For more information on this Research Task Component see Appendix III.

3.2.2 Population Dynamics, Dispersal and Demography of California Gnatcatchers in Orange Co., California (1998 Progress Report)

3.2.2.1 Background

The results presented here provide basic information about the biology of California gnatcatchers, a songbird species central to southern California's coastal sage scrub habitat conservation planning effort.

A critical aspect of the State of California's Natural Community Conservation Planning (NCCP) program is the central role that science is intended to play in the formulation of land-use planning decisions and policies (California Department of Fish and Game and California Resources Agency 1993). By applying the principles of modern conservation biology to data on the distribution, ecology, and population dynamics of selected plant and animal species, an important objective of the NCCP is to design regional reserves that will ensure the long-term viability of rare and declining habitat types (O'Connell and Johnson 1997). Such a "proactive" conservation approach, if successful, may potentially halt the decline of sensitive species dependent on the habitats being considered, and thereby reduce the need to protect biodiversity through the cumbersome regulatory framework afforded by endangered species laws (Atwood and Noss 1994). Conversely, the NCCP may also identify areas that are scientifically determined to be less important from a biological standpoint, and where economic development may consequently proceed without fear of triggering further additions to federal or state endangered species lists.

The pilot project of the NCCP program has focused on a plant community known as coastal sage scrub (Reid and Murphy 1995), which is patchily distributed in southern California in the coastal lowlands west of the Transverse and Peninsular ranges. Historically, coastal sage scrub was a dominant feature of the southern California landscape, where it occurred widely in a natural matrix that also included grassland, chaparral, and oak woodland communities. Today, as a result of urban and agricultural impacts, 70-90% of the historic acreage of coastal sage scrub is estimated to have been lost (Westman 1981; O'Leary 1990), and those tracts of scrub that remain in the region generally occur as islands surrounded by ever-increasing urban development. Habitat loss and fragmentation have caused nearly 100 species and subspecies of plants and animals belonging to the coastal sage scrub community to decline to the point that federal and state wildlife agencies have formally designated them as endangered or threatened, or identified them as potential candidates for such listing (Atwood 1993).

The NCCP coastal sage scrub Scientific Review Panel selected three target species to use as the focus of conservation planning efforts for this habitat type: California gnatcatcher (Polioptila californica), cactus wren (Campylorhynchus brunneicapillus), and orange-throated whiptail (Cnemidophorus hyperythrus) (California Department of Fish and Game and California Resources Agency 1993).

Although different or additional species are, in practice, being used as surrogates for coastal sage scrub conservation planning in various areas of southern California, virtually all NCCP efforts that have been initiated to date have included maintenance of viable populations of California gnatcatchers as a principal objective. Sound ecological and behavioral information about this species will thus play a critical role in the preparation of NCCP plans and contribute to evaluation of the program's success.

3.2.2.2 Objectives

This study focuses on three objectives of direct importance to conservation and management efforts, and describes how long-term, detailed demographic studies can potentially clarify conservation issues affecting coastal sage scrub reserves. These objectives include:

- Collecting data on factors affecting patterns of dispersal by California gnatcatchers.
- Determining what factors influence annual variation in California gnatcatcher reproductive success, survivorship, and territory size, and what the implications are for research aimed at monitoring populations of these species.
- Developing GIS data layers delineating the extent of coastal sage scrub vegetation and the distribution of California gnatcatchers to examine factors affecting observed differences in California gnatcatcher densities, and attempt to identify those habitat characteristics that determine whether areas act as population sources vs. sinks.

3.2.2.2 Methods

Study Areas

This report includes information collected from six study sites in coastal Orange Co., California.

Population Survey

All major areas of natural habitat located in the six principal study sites were surveyed for breeding California gnatcatchers between February and June of each year of the study (1995 – 1998). Surveys were generally conducted before 11:00 a.m. and after 4:00 p.m., under weather conditions deemed acceptable in terms of wind and temperature. Tape recordings of gnatcatcher vocalizations were used to elicit responses. In areas where closely adjacent territories of unbanded birds posed potential confusion over the number of pairs actually present, teams of biologists would revisit the site in order to obtain simultaneous observations of all birds in question. Population estimates were based on observations of uniquely banded birds, the locations of simultaneously active nests, or simultaneous observations of unbanded birds. Survey intensity greatly exceeded the minimum effort required by U.S. Fish and Wildlife Service protocols (USFWS 1997).

Breeding Biology and Reproductive Success

Territories of focal pairs were visited between one and three days per week, beginning in early March and continuing into July or August. Nests were located through direct observation of nest building, nest exchanges, or feeding of nestlings. All successful nesting attempts of each of these focal pairs were detected. The number of juveniles fledged from each successful nest was based on counts, usually of banded birds, that were made one to five days after fledging.

To minimize potential impacts associated with monitoring activities, visits by biologists to gnatcatcher nests were generally limited to two to three occasions from the beginning of nest building to fledging. The initial visit was made when feeding of nestlings was first observed, in order to estimate the age of juveniles that were present and thereby schedule a follow-up banding visit. This second visit was then made when the gnatcatchers were approximately eight days of age; handling nestling gnatcatchers before this age was deemed impractical due to the birds' small size. We made no effort to expand the presently available data on clutch size, as our primary goal was to determine the total number of fledglings produced annually by each pair. Nests were not visited when western scrub-jays (Aphelocoma californica), loggerhead shrikes (Lanius ludovicianus), or brown-headed cowbirds (Molothrus ater) were seen nearby.

Japanese mist nets were used to capture adult and fledgling gnatcatchers for banding; birds were usually attracted to the vicinity of the nets by playback of recorded vocalizations. Two colored plastic leg bands were used in conjunction with the numbered USFWS.

Dispersal Behavior

Direct-line distances were used as the basis for evaluating the dispersal behavior of juvenile California gnatcatchers. Banding and resighting locations were described within a 1000-foot by 1000-foot grid pattern superimposed over each study area; distances were calculated between the centers of each of these grid cells using Arc/INFO's POINTDISTANCE function, and rounded to the nearest 0.1 km.

Survivorship

Survivorship estimates for adults and juveniles were calculated between the nesting seasons of

- 1993 – 1994
- 1994 – 1995
- 1995 – 1996
- 1996 – 1997
- 1997 - 1998.

Birds were included as being alive in a given year even if they were not actually recorded until following years.

3.2.2.3 Outcomes

Population Size and Distribution

Seventy-two to 96 breeding pairs of California gnatcatchers were found in the coastal Orange County study sites during surveys conducted from 1993 to 1998. Seventy-two pairs were located in 1998. Apart from a one-year increase that occurred during 1994, likely as a result of immigration of birds displaced by the Laguna fire of October 1993 (Atwood et al., 1999), populations in our study areas were essentially stable from 1993 – 1998.

Reproductive Success

Average gnatcatcher reproductive success in coastal Orange County from 1995 – 1998 was 2.64 fledglings produced per pair per year. There were no significant annual differences in gnatcatcher reproductive success among these years (Kruskal-Wallis test; H corrected for ties = 2.26, P = 0.52).

Reproductive success was compared between study sites dominated by Artemisia californica and sites where the coastal sage scrub community had a stronger chaparral component (including frequent dominance by Salvia mellifera). During each year of the study, there were no significant differences in the number of fledglings produced between these two categories of sites (Mann-Whitney U-test, $P > 0.05$). Other aspects of reproductive behavior have not yet been fully analyzed, but there was a significant difference in 1998 between Artemisia-dominated and Salvia-dominated sites in the frequency of occurrence of pairs with 0, 1, and 2 successful nesting attempts (Likelihood Ratio chi-square = 7.640, $P = 0.02$), with the relative rarity of 2 successful nesting attempts in Salvia-dominated sites especially deviating from expected.

Survivorship

California gnatcatcher survivorship data was summarized for adult and juvenile cohorts known to be alive in 1993, 1994, 1995, 1996, and 1997. Average survivorship was 0.197 for juveniles and 0.568 for adults (both male and female) based on combined data from both study areas. Because dispersing juveniles may easily move into areas where they are unlikely to be encountered as part of our research efforts, estimates of juvenile survivorship must be considered minimum values. In particular, because the Palos Verdes Peninsula functions as a closed system in comparison to Orange County study sites, estimates of juvenile survivorship to year one are probably more accurate from Palos Verdes than from Orange County.

Comparisons of survivorship estimates between Orange County and Palos Verdes failed to detect any significant difference between the two localities for adults of either sex (Mann-Whitney U-test, $P > 0.10$). Based on combined data from both study areas, there was no difference in mean survivorship estimates of males ($x = 0.52$, s.d. = 0.173, $n = 9$) vs. females ($x = 0.62$, s.d. = 0.159, $n = 9$).

Dispersal Behavior

No significant difference was found between Orange Co. and the Palos Verdes Peninsula in the dispersal distances of juvenile female gnatcatchers (Wilcoxon rank sum test, $Z = 1.48$, $P = 0.14$) or of juvenile male gnatcatchers (Wilcoxon rank sum test, $Z = -0.78$, $P = 0.43$). Consequently, data were combined from the two areas in order to increase sample sizes. No significant difference was found between the sexes in dispersal distance (males: mean = 2.95 km, s.d. = 2.68, range 0.0 - 10.2 km, $n = 92$; females: 2.48 m, s.d. = 2.14, range 0 - 10.1 km, $n = 104$) (Wilcoxon rank sum test, $Z = 0.99$, $P = 0.32$).

Annual differences in mean distances dispersed by juvenile gnatcatchers might conceivably reflect year-to-year differences in habitat saturation. For example, in years when regional population levels are high, relatively few areas of suitable and unoccupied habitat are presumably encountered by dispersing juveniles, thus requiring more extensive searches which result in longer average dispersal distances. In years when population levels are low, dispersing juveniles may succeed in discovering suitable, unoccupied habitat relatively near to their natal territories, resulting in lower average dispersal distances. Although there may be other factors involved which we have not yet addressed, this hypothesis appears to be supported by data collected in Orange County from 1994 to 1998. Juveniles fledged in Orange Co. in 1994, when gnatcatcher population levels were regionally elevated (Erickson and Miner 1998, Atwood et al. 1998a,b), had longer dispersal movements than cohorts fledged in 1995, 1996, and 1997 (Kruskal-Wallis Test, Chi-square = 10.1896, $P = 0.02$).

3.2.2.4 Conclusions

. These data are of major importance in evaluating existing conservation plans, guiding the preparation of new plans, and contribute to the ongoing refinement of habitat and species management objectives. These data go far beyond the typical "monitoring" activities that have too often characterized NCCP research efforts. While such monitoring projects are not without their value, mere counts of pair numbers will simply not provide planners, land managers, or regulatory authorities with the tools needed to understand and adaptively respond to specific conservation challenges (Science & Policy Associates 1997). This study (including now-terminated work on the Palos Verdes Peninsula) represents one of the only ongoing efforts aimed at collecting demographic and behavioral data for California gnatcatchers. Because of the major time investment involved in establishing uniquely-banded populations of known-age, known-natal area birds, and the value of such a study population in addressing regional conservation issues, the Palos Verdes / Orange County (coastal) project represents a critical research element contributing to the State of California's NCCP efforts.

For more information on this Research Task Component see Appendix IV.

3.2.3 Conservation and Management of Coastal Sage Scrub Habitat

3.2.3.1 Objectives

The aim of this task was to update the California Gnatcatcher model that was developed in a previous project, applying the gnatcatcher's interaction with its habitat to determine the best method to maintain management and conservation of coastal sage scrub habitats. The previous model was published in the journal *Conservation Biology* (Akçakaya and Atwood 1997). Changes were made to this previous model, using two years of new data that became available since the publication of the 1997 article.

3.2.3.2 Methods

The model is a spatially explicit, stage-structured, stochastic model of the California Gnatcatcher metapopulation in central and coastal Orange County. Model development started with a compilation of habitat data on vegetation and topography, and demographic data on survival, reproduction, and dispersal of the species.

The habitat data were used in a stepwise logistic regression, which estimated, for each cell, the probability of finding a gnatcatcher pair at that location, and thus reflected the suitability of the habitat. The resulting habitat suitability map was then validated by estimating the regression function from half the landscape, and using this function to predict the habitat suitability for known locations in the other half. The validated habitat suitability map was analyzed to calculate the spatial structure of the species' metapopulation (i.e., the number, size, carrying capacity, and location of its subpopulations), based on the distribution and quality of the habitat.

At the population level, the model for the California Gnatcatcher incorporated demographic data on survival, reproduction, and environmental variability for each population inhabiting a habitat patch. At the regional (metapopulation) level, it incorporated data on spatial factors that are important determinants of the risk of decline, including dispersal among patches, catastrophes, and spatial correlation of environmental fluctuations among the patches. The model was implemented in RAMAS® GIS 3.0, which is designed to link landscape data from a geographic information system (GIS) with a metapopulation model.

In the current update of the model, the only change in the patch structure was a “protected area mask” applied to the habitat suitability map, to mask non-reserve areas while allowing the proposed reserve areas to show through.

Estimates of demographic parameters were updated in several ways:

- New data from 1997 and 1998 were used, increasing the number of years of accumulated data from three to five.
- More of the parameters from Orange County rather than Palos Verdes were estimated.
- Parameter estimates for previous years were refined using data that were updated due to the continuing process of data entry and editing.

3.2.3.3 Outcomes

The new habitat suitability map included only the protected habitat, and assumed that the non-reserve areas will eventually become unsuitable for nesting, although they can be used for dispersal among reserve areas. Given this habitat map, the program found nine habitat patches (clusters of suitable cells within neighborhood distance of each other). The two largest patches made up about 86% of the total area of all patches. The total carrying capacity was 795 females, or (at stable distribution) 329 adult females. The total initial abundance was 636 females, or 263 adult females.

With the medium parameter estimates, the model predicted a substantial decline, but a low risk of extinction of the gnatcatcher populations. The risk of falling below the metapopulation threshold of 30 females within 50 years was about 10%. Although the extinction risk was low, the risk of a substantial decline was high.

3.2.3.4 Conclusions

Because of the uncertainty in most model parameters, and the sensitivity of results to these uncertainties, we suggest that the results should not be interpreted in absolute terms. Specifically, it would be inappropriate to use the results of this model to conclude that gnatcatcher populations in Central / Coastal Orange County are either threatened by extinction or secure from such a threat. There is too much uncertainty to predict with confidence what the population size will be in 50 years, or what the risk of extinction might be. Despite this uncertainty, the model can potentially have practical application in several areas. . These applications also indicate future research directions.

3.2.3.5 Recommendations

The research directions outlined below will lead to a set of practical tools for evaluating options for the management and conservation of the coastal sage scrub community.

Planning fieldwork and refining models with model-driven field research

Most parameters of a population viability analysis (PVA) model are known with a certain amount of uncertainty. Further fieldwork may yield data to narrow down these uncertainties and thus make model predictions more accurate and reliable. Analysis of the sensitivity of model results to various parameters provides guidance about what kind of data would be most efficient in terms of making the model predictions more reliable.

Expanding geographic coverage to southern California

An important limitation of the model is its geographic coverage. The coastal sage scrub in the study area may be connected to similar habitat in southern Orange County and elsewhere. Thus, the limits of the study area in central and coastal Orange County are somewhat arbitrary. One potential improvement to the model involves expanding it to include the populations of California Gnatcatcher in other areas.

Designing reserves

Reserve design, especially in a region as crowded as southern California, is determined by a large number of biological, economical, political, and social constraints. These constraints limit the number of feasible reserve configuration options. Metapopulation modeling can help provide scientific guidance to the process of reserve design by showing the environmental managers the ecological consequences of each option. This can be done by calculating the risk of decline for selected species under each reserve design option. Each reserve design option will then be associated with an economic (cost) and an ecological (risk of decline) consequence. This approach can also be used for other aspects of reserve design, such as designing habitat corridors and other connecting habitats, or adding small, “stepping-stone” habitat patches to existing reserves.

Testing management options

In principle, all possible management actions can be represented as changes in habitat suitability or demographic parameters, once the effect of these management actions is described in terms of model parameters. The consequences of these changes are estimated by the model in terms of the viability of the species, and then used to rank alternative management actions, to prioritize conservation measures, and to evaluate the relative importance of different parameters.

Assessing human impact

Assessment of human impact can be done in a way similar to the evaluation of management options. Each impact affects the population in a specific way. These effects can be quantified as changes in model parameters or structure. For example, habitat loss may decrease the carrying capacities of affected habitat patches; fragmentation can change the spatial structure of the metapopulation; pollution and widespread degradation of habitat quality may affect vital rates such as survival and fecundity; and geographic barriers may lead to both fragmentation and a decrease in connectivity (dispersal rates among patches).

Reserve design and management from a multi-species perspective

The habitat-based metapopulation modeling approach described above can be applied to a list of selected (e.g., “indicator,” threatened, or sensitive) species. This results in habitat suitability maps and metapopulation models for all species in the list. The outcomes of the model simulations are used to estimate the risk of extinction or decline of the species in the whole region, as well as the importance of each location for the viability (persistence) of the species. Each of the individual habitat suitability maps can then be combined into a single aggregate map (a "multi-species conservation value" map) that expresses the worth, in conservation terms, of the locations. The habitat suitability maps can be combined mathematically by using a weighted average of all of the maps (Akçakaya 1999).

It is important to note that Habitat Conservation Plans, as well as plans for the management and design of multiple species reserves, will work only if they are based on sound science. One of the most powerful scientific tools that land managers and decision-makers can use is PVA of selected species. These methods can be used to:

- Aid various types of decisions in the design and management of multi-species reserves.
- Guide fieldwork in order to use resources in the most efficient way.
- Support reserve design decisions with a science-based comparison of the design options with respect to their ecological and economic consequences.
- Evaluate management options and impacts in terms of their effect on the viability of selected native species.
- Identify ecological "hot-spots," i.e., areas of high conservation value from a multiple species perspective.

For more information on this Research Task Component, see Appendix V.

3.2.4 RAMAS® Ecological Risk Model for Desert Tortoise

3.2.4.1 Background

The desert tortoise, federally listed as threatened, is by both extrinsic (e.g. habitat destruction / degradation, drought) and intrinsic (e.g. low juvenile survival, delayed maturity) factors. The greatest threats to the tortoise and its long-term survival appear to be human intrusion in the desert tortoise habitat. Long-term data indicates that the populations of this species are declining, although some regions appear more vulnerable than others.

The desert tortoise is a long-lived herbivore restricted to arid habitats in California, Nevada, Arizona, Utah, and northwestern Mexico. Desert tortoises spend 98% of their time in burrows, which they excavate and defend, emerging in the spring to feed, mate, and lay eggs. Most desert tortoises reach sexual maturity at approximately 180mm in carapace length (i.e., 8-20 years of age). Reproductive output of females varies from 0-3 clutches per season with 1-14 eggs per clutch, depending on winter rainfall and forage availability. Regional abundance estimates vary. In the western Mojave, some declines in desert tortoise numbers have been documented. In other regions, such as the eastern Mojave, populations appear to be stable. Tortoises move extensive distances for foraging and finding mates, but freeways are deadly for the tortoise and restrict these movements. The fundamental problem is that the desert tortoise is widely distributed, long-lived, and has delayed sexual maturity, making this species vulnerable to human impact and habitat destruction and loss.

3.2.4.2 Objectives

This project focused on the potential effects on the desert tortoise metapopulation resulting from construction of transmission lines in tortoise habitat. Construction of transmission lines is likely to reduce the amount of available suitable habitat for the tortoise and were simulated in the model as a reduction in the carrying capacity. Another potential effect of transmission lines is the increase in the number of raven predators. Recent studies have suggested that raven density increases along utility corridors and that ravens are a major predator of juvenile desert tortoises. As such, ravens pose a threat to the long-term viability of local populations. In the model, we simulated the impact of raven predation using a reduction in the survival of tortoises that were <100mm in carapace length.

The goal was to build an assessment tool for the evaluation of the population-level risks to the desert tortoise from utility transmission line siting or modification, or from maintenance operations associated with transmission lines in the Mojave Desert of California. Specifically we examined factors affecting the long-term viability of the desert tortoise in California, Utah, Nevada, and Arizona using a stochastic metapopulation model.

3.2.4.3 Methods

A regional-scale metapopulation model for the desert tortoise is an excellent tool to address long-term management and conservation issues. Such a model includes:

- Length / age-specific demographic parameters
- Abundance estimates for Mojave Desert tortoise populations
- Estimates of annual variability in demographic parameters
- Environmental stochasticity
- Density dependence
- Effects of impact factors such as predation or habitat destruction / loss.

Data on annual rates of survival and reproduction, population abundance, dispersal probability, and density dependence were required for this model.

Extensive mark-recapture studies have been conducted at the Goffs study site in California in the Eastern Mojave Desert. Much of the demographic information available on desert tortoise comes from these studies. Additional studies have been conducted on land owned by the Bureau of Land Management (BLM) scattered throughout the range of the desert tortoise. Tortoises west of the Colorado River differ ecologically and genetically from populations east of the river, and are currently listed as threatened by the USFWS. So, for this study we included only those populations that were west of the Colorado River, in California, Nevada, Utah, and Arizona.

Using RAMAS® GIS (v.3.0) for Windows 95, we incorporated the available data on survival, growth, fecundity, and the year-to-year variability of the demographic rates from empirical studies at Goffs, California on BLM lands, and from published literature. We constructed a female-only, carapace-length-based, eight-stage population model. In the model, only female tortoises larger than 180mm in carapace length reproduced, based on clutch data from Goffs. In the Desert Tortoise Recovery Plan (1994), 12 Desert Wildlife Management Areas (DWMAs) were designated in six Recovery Units. We used these DWMAs as the basis for the location of the desert tortoise populations west of the Colorado River.

These DWMA-based populations were large and comprised of both suitable and unsuitable habitats for the desert tortoise. Using a GIS habitat suitability analysis based on the vegetation coverage (GIS data obtained from University of California Santa Barbara (UCSB) Gap database, which was partially funded by SCE, the USGS National Gap database, and the Mojave Desert Ecosystem Database Project), the area that was suitable for tortoises was estimated in square kilometers. These were digitized in ArcView in two different ways. In the unfragmented scenario, it was assumed that any populations that were contiguous represented a single population. With this assumption, the 12 DWMA's become eight desert tortoise populations. Alternatively, in the fragmented scenario, we assumed that roads and rivers represented an insurmountable barrier to tortoise dispersal. The map, therefore, includes 26 distinct polygons or populations for desert tortoises in California, Utah, Nevada, and Arizona.

There were two sources of density estimates for these populations. Between 1977 and 1989, tortoises were captured and measured at 20 BLM plots scattered throughout the region. These captures were used to estimate densities. In the Desert Tortoise Recovery Plan (1994), a range of densities was given for each the 12 regions. For populations that included parts of more than one DWMA, the average density of the individual DWMAs was chosen for the population. The maximum DWMA density estimate, or the BLM maximum density estimate, if available, was used to calculate the carrying capacity for each population.

In the model, some assumptions were made about dispersal among populations. In the fragmented metapopulation, tortoises did not cross the roads, i.e., no dispersal was allowed across the highways. Within a year, a maximum of 5% of a population could migrate equally into the neighboring populations. In the fragmented metapopulation, tortoises in populations seven and eight were completely isolated from all other populations by roads, but tortoises could travel from population six to population ten and vice versa.

Little is known about density dependence in desert tortoise populations. Tortoises use burrows and do defend them, which indicates a degree of territoriality. As a cautious approach to density dependence in the absence of data, the model includes a density ceiling or carrying capacity (K), which was assumed to be the maximum observed density in field studies. As a less pessimistic alternative, simulations were run with scramble competition for populations with fecundities greater than zero, and with the ceiling described above for the remaining (severely declining) populations. The carrying capacity (K) was specified for all populations as described above and the maximum population growth rate (R_{max}) was either 1.025 or 1.05 (i.e., an average annual increase of 2.5 or 5%).

In addition, we customized the RAMAS® GIS model to address specific ecological issues, e.g., raven predation, and utility activities such as maintenance, construction, and siting. Assuming that a single line running through a population eliminated 116.5km^2 of suitable habitat (based on literature estimates), the potential effects of the new transmission lines can be modeled as a reduction in the carrying capacity of the affected population. We examined four possible siting scenarios: one line passing through each of the five largest populations, one line passing through each of the five smallest populations, one line passing through each of the fifteen smallest populations, and one line passing through each of the twenty six populations. In each affected population, we reduced the carrying capacity by 116.5km^2 while keeping all other parameters the same as in the previous models. In the metapopulation model, the impact of additional mortality on juveniles was incorporated to assess the impact an increasing number of ravens might have on specific tortoise populations. Since there are no direct data that indicate the actual rate of predation, we assumed that ravens would increase the mortality of the classes 0-2 (less than 100mm in carapace length) either 10% or 20% annually in an affected population. For these predation scenarios, we assumed that only the youngest three classes were affected and that no habitat was lost.

The analysis of the metapopulation dynamics with the model described above consisted of a series of simulations. Each simulation had 10,000 replications, and each replication projected the abundance of each population for 100 time steps (years). The resulting graphs, available in Appendix VI, show risk of decline (within the simulated time horizon) as a function of amount of decline. Statistical significance was estimated using the Komogorov-Smirnov test for the maximum vertical distance between two terminal percent decline curves.

3.2.4.3 Outcomes

The model makes a number of predictions. Fragmentation, habitat loss (reduction in carrying capacity) and raven predation increase the risk of a decline in abundance for the tortoise metapopulation. The magnitude of the increase in risk from these factors is dependent on (1) the magnitude of the impact (e.g., 10% vs. 20% predation), (2) which populations are affected by the impact (e.g., large versus small populations), and (3) the assumptions about density dependence. The largest increase in risk due to habitat loss occurred when applied to only the smaller populations, i.e., an 18% increase compared to comparable scenarios with no habitat loss. For raven predation, the largest increase (10-54%) occurred when applied to only the larger populations, depending on the level of predation, and the risk of a decline compared to comparable scenarios with no additional predation.

The results of this model suggest that the potential impacts of transmission line siting and maintenance were dependent on which populations were affected, but the effects were usually moderate. The baseline risk of a 50% decline in the metapopulation abundance, though, was quite high with no additional impacts except under the most optimistic density dependence assumptions. This finding supports empirical studies indicating that these populations are experiencing a large decline in abundance. The model and the results would be strengthened by additional data on density dependence in natural populations, such as carrying capacity and maximum growth rate, and on the effects of raven predation.

3.2.4.4 Recommendations

As this analysis has shown, ecological risk assessment is a valuable management tool that allows comparison of alternatives even with limited data, and highlights future research needs. Additional empirical studies of the tortoise are warranted, especially in the area of density dependence and predation. Given the assumptions in the model, though, the potential impact of a new transmission line may be estimated with this technique given the specific location and extent of the line, and compared with alternative plans. Also, as additional data are accumulated, the metapopulation model can be easily modified to incorporate the new information and assess the effects.

For more information on this Research Task Component, see Appendix VI.

3.2.5 The Metapopulation Model as an Educational Tool: Providing Internet Access to RAMAS® GIS Software

3.2.5.1 Background

In this project, we developed a version of RAMAS®, downloadable from the World Wide Web (WWW), which allows users to run metapopulation models based on the real-world examples of the desert tortoise and the California gnatcatcher. These models serve as an excellent educational tool. By placing a version of the metapopulation model on the WWW, members of the public may test the alternatives for themselves. In addition, the models serve as a vehicle to SCE's and the Electric Power Research Institute's commitment to environmental issues and their research efforts. Users can pose a question, examine the modeling predictions, and draw their own conclusions. Students will have the opportunity to learn about the methods and tools used for PVA and risk assessment. Not only does this demonstrate the efficacy of the technique used, but it allows a broader public participation in important regional issues.

3.2.5.2 Objectives

The goal of this project was to develop an interactive web site that allows users to accomplish three things:

- Learn about the research that SCE has funded on conservation of the California gnatcatcher and the desert tortoise.
- Explore the methods and results themselves by downloading the software, using the input provided, and running the models themselves.
- Learn about current methods in conservation, including PVA, and their applications to real-world issues.

3.2.5.3 Methods

The program RAMAS® GIS was modified and compressed to be readily downloadable off of the Internet. Sample data files that included the necessary demographic and spatial elements for use in RAMAS® GIS were created for the desert tortoise and the California gnatcatcher metapopulation models. Help instructions for the program and a tutorial that guides users through the provided example files were developed.

A web site was created on the WWW to host the demo version of RAMAS® GIS (*http://www.ramas.com/demo/tortoise/index.htm*) and the additional sample files, data, support documents, and general guidance on the use of the program and how to interpret the results. Included on the site are the background materials, description of data utilized, and an interactive version of the metapopulation model. The web site provides important information for potential users of RAMAS® GIS, such as guidance on the use of the program and on the interpretation of the risk results of the program. The documents are in a format that is suitable for the web and can be downloaded for the user's convenience. Additional information is provided on the specific examples that are available for use in the program.

For the desert tortoise project, a slide show was created. In the slide show, basic tortoise biology is explained, as is why it is vulnerable to human intrusion into its habitat. Some of the issues that face desert tortoise populations in their habitat are outlined, and one approach to addressing these issues is described. The slide show then demonstrates step-by-step how the metapopulation model was constructed, parameterized, and run in RAMAS® GIS. Some example results are shown and discussed, and the slide show finishes with some conclusions and recommendations.

For the California gnatcatcher portion of the web site, some of the relevant issues for the species are presented. The basic approach to these issues is described and the results are displayed. Details of the model, its parameters, and its construction are provided in a tutorial where users examine the model in RAMAS® GIS, which they have downloaded.

3.2.5.4 Outcomes

There are three sections to the web site that are launched from the main page (*index.htm*). A schematic diagram of the web site is shown in Figure 1.

- Part 1: Conservation and Management of Coastal Sage Scrub
  - Project description and sample file tutorial (accessed via files: *gnat.htm* and *gnattutr.htm*, respectively)
  - Sample model files (*gnatmdls.zip*) that compare three hypothetical management strategies
- Part 2: Desert Tortoise Metapopulation Dynamics (Phase II)
  - Project description in the form of a slide show (accessed via file: *title.htm*)
  - Sample model files (*tortmdls.zip*) that examine seven different parameter sets
- Part 3: The metapopulation model as an educational tool
  - RAMAS® demo program available (*rgdemo.exe*)
  - Help files in Acrobat form (*readme.pdf*) or as a text file (*readme.txt*)
  - Two additional sets of models (*gnatmdls.zip* and *tortmdls.zip*)

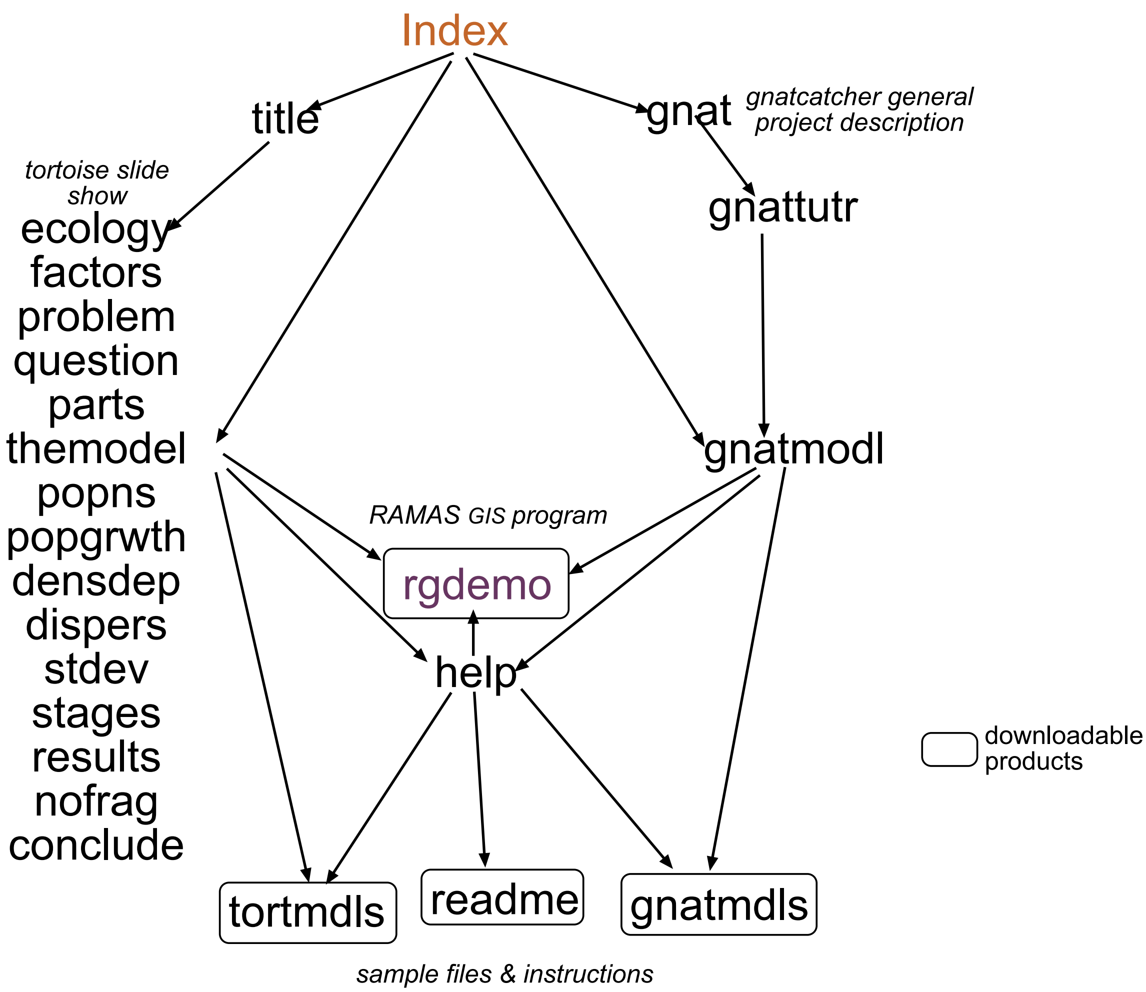

Figure 1. Schematic diagram of the RAMAS® web site

3.2.5.5 Conclusions

We believe this web site will serve as an excellent educational tool. It also highlights SCE's commitment to environmental research and conservation of native species. This research utilizes state-of-the-art communication media (the internet) to deliver the state-of-the-art conservation technology (RAMAS® software) and emphasizes the application of technology to solving real-world problems.

For more information on this Research Task Component, see Appendix VII.

3.2.6 Comparison of IUCN and USFWS classifications of threatened species

3.2.6.1 Background

The Endangered Species Act (ESA) was implemented in 1973 to prevent extinction of animals and plants through the protection of their ecosystems and the development of specific conservation programs (USFWS 1998). The ESA authorizes officials to categorize species facing risk of extinction as either endangered or threatened, based on the magnitude of extinction risk.

Federal agencies are then obligated to carry out conservation measures to protect these species by imposing regulations to preserve critical habitat or to restrict harvesting levels as deemed essential for their conservation.

Assessing the extinction risk of species is imperative for implementing effective conservation strategies and for apportioning limited financial and human resources for species conservation. The determination to list a species as endangered or threatened is, therefore, one of the most critical steps for reaching the objectives of the ESA. Yet, the protocol for prioritizing taxa for protection has been criticized by some in the scientific community as being arbitrary because there are no explicit guidelines by which these decisions are made. The use of biological criteria in the decision-making process is inconsistent, and descriptive variables often receive more consideration than quantitative variables.

2.3.6.2 Objectives

Despite criticisms of the USFWS listing protocol, few quantitative or systematic analyses of the system have been conducted. In this study, the USFWS listing protocol is evaluated by comparison with another system used by the international conservation organization known as the World Conservation Union (IUCN). Risk classifications of 60 species were examined under both the USFWS and the IUCN systems and compared.

3.2.6.2 Methods

Sixty animal species native to California were classified according to criteria from the IUCN and the USFWS. The degree of correspondence between the classification systems was then examined. IUCN classifies each species into one of four categories (Critically endangered, Endangered, Vulnerable, and Lower risk) based on ecological variables such as number of mature individuals, recent declines, geographic distribution, and extinction risk. USFWS classifies species at risk into one of two categories (endangered and threatened) based on magnitude and immediacy of threat and taxonomic uniqueness.

If a species was previously evaluated by IUCN, its status was taken from IUCN. Species chosen that were not already listed by the IUCN were classified according to the IUCN criteria. Information concerning the populations of each species and their habitat was collated from the scientific literature and from USFWS status reports. This information was then incorporated into RAMAS® RedList (Applied Biomathematics, Setauket, NY), a program that uses numerical thresholds of ecological variables to classify species according to IUCN criteria. Twenty-four of these species were not listed by the USFWS (USFWS 1999) and could not be evaluated confidently because the USFWS criteria for listing species are not explicit.

A comparison was made between the IUCN and the USFWS classifications. It was assumed that IUCN's lower-risk category corresponds to the species not listed by the USFWS. The highest-ranked categories of IUCN, (critically endangered and endangered) were assumed to correspond to the USFWS category endangered. Because there are fewer categories under the USFWS system, it was also assumed that threatened corresponds to both endangered and vulnerable categories of the IUCN. The degree of disagreement between classification systems was determined from the proportion of species that did not fall within the corresponding categories.

3.2.6.3 Outcomes

A comparison of the two systems revealed a large degree of correspondence between the criteria used by USFWS and by the IUCN. The only USFWS criterion that does not have an explicit counterpart in the IUCN criteria is “Not adequately protected by present laws and regulations” (FWS criterion 4). However, those species that are not adequately protected will have:

- Declining area of occupancy, area, extent and / or quality of habitat, number of locations or subpopulations or mature individuals (IUCN criterion B2), or
- Continuing decline in numbers of mature individuals, combined with fragmentation (IUCN criterion C2), or
- A high risk of extinction (IUCN criterion E).

Thus, although protection by existing laws and regulations is not an explicit part of the IUCN criteria, the effects of the lack of such protection are reflected in at least three of the criteria.

The correspondence between the USFWS and the IUCN listing categories were compared for 60 native California species. The listing status of 19 of them (31.7%) did not fit into corresponding categories of the IUCN and the USFWS. Eight species were listed in a higher endangerment category by the USFWS, while 11 were either not listed (9) or listed in a lower threat category (2) by USFWS. Of the nine species that were not listed by the USFWS, it is unclear how many have not been evaluated and how many were evaluated but considered to have a low extinction risk. When these species were not considered in the comparison, ten of the remaining 51 species (15.7%) were listed in USFWS and IUCN categories that did not correspond to one another.

3.2.6.4 Conclusions

The inconsistent use of biological criteria and heavy reliance on qualitative variables by the USFWS result in a low correspondence with the IUCN system and with its own “degree of threat” ranking under the recovery priority listing system. The low correspondence with the IUCN categories was found in spite of the assumption that each USFWS category corresponds to two IUCN categories.

The IUCN listing system has several advantages over the USFWS protocol. The IUCN listing process was developed under wide consultation and is recognized internationally by the public and scientific community. The lists of threatened species developed by IUCN are among the most widely used by conservationists around the world. The IUCN criteria were designed to detect risk factors for organisms of widely different taxonomic groups. While all criteria might not be relevant for a particular taxon, there are criteria relevant for assessing extinction threat of all groups (except microorganisms).

3.2.6.5 Recommendations

Resources for conservation of species are limited. It is, therefore, imperative that decisions are made carefully to focus on species that will receive the most benefit from conservation agents. Also, many species at risk of extinction cannot afford an inefficient listing protocol. These considerations are mentioned in the Endangered Species Act of 1973, yet the present process is both slow and subjective. To revise the federal system, we suggest a new decision making process be developed that is similar in structure to the IUCN system that could easily be modified to satisfy the specifications of the ESA.

For more information on this Research Task Component, see Appendix VIII.

3.3 California Habitat Evaluation

3.3.1 Procedures for Creation and Use of ADAR-Based Vegetation Maps to Support Habitat Management

3.3.1.1 Background

This report presents results of research to develop methodologies for mapping and monitoring critical California habitats using Airborne Data Acquisition and Registration (ADAR), a high-resolution airborne multi-spectral imaging system. The study is part of a long-term research program initiated by SCE as early as 1995. SCE's California Habitat Evaluation Research Program began with research to apply ADAR technology to monitoring coastal wetland habitats (Phinn et al, 1996). In its second stage, the program extended the use of ADAR's imaging capabilities to the mapping of coastal sage scrub, a habitat of special interest in Southern California and the subject of the State of California's ambitious Natural Communities Conservation Program (NCCP). Research in this second stage demonstrated that ADAR can be used to identify and map components of the coastal sage scrub community, as well as related communities such as chaparral, grassland, sycamore woodland, etc. (Brewster et al., 1998). The research described in the present report, conducted during the period from June 1998 to June 1999, represents the third stage of the program, with the goals of further enlarging the mapping and monitoring capabilities of applied ADAR technology and of bringing the technology closer to operational (rather than experimental) use. The specific objectives of stage-three research are described in detail in the section that follows.

The fourth stage of the California Habitat Evaluation Research Program, designed to follow upon the now complete third stage, includes goals of adding conifer forest and related woodland communities to the repertoire of habitats that can be mapped effectively using ADAR, and making time-sequence (multi-year) monitoring fully operational.

The overall goals of the research program, and of the present study in particular, serve several needs. Mapping and monitoring of critical habitats is a vitally important function to managers of habitat preserves. Development of ADAR technology as a mapping and monitoring tool therefore supports the conservation goals of the State's NCCP. As a pioneering "habitat-based" conservation program, the NCCP is just now entering its implementation phase, and the newly entrusted managers of participating preserves recognize a need for new, cost-effective technologies to assist their efforts (Almanza, 1998). The availability of ADAR technology to support management of preserves will not only assist SCE, as a permittee with coastal sage scrub habitat in NCCP preserves, but can also assist other NCCP participants (such as San Diego Gas & Electric) as well as the regulatory public agencies (California Department of Fish & Game and USFWS). Mapping and monitoring tools also have the potential to serve conservation needs within California. As multi-species and habitat-based conservation programs proliferate in California, the demand for cost-effective habitat management tools will increase. As a rapid, efficient method for collection of digital, landscape-level data, ADAR has the potential to provide the real-time data necessary to drive monitoring and management tools such as RAMAS® and other meta-population models. Development of mapping and monitoring tools through this research lays the groundwork for a wide range of capabilities that comprise the toolbox for managing California's legacy of habitat preserves.

3.1.1.2 Objectives

The objectives of research conducted in 1998-99 are:

- To enlarge the mapping capabilities of ADAR methodologies to include numerous habitat types not previously established within the technology's repertoire. The additional habitats (several dozen) were studied through two new study sites, each offering a range of plant communities not found within previously studied sites. These two sites, Hidden Ranch (or Black Star Canyon) and the Etiwanda Alluvial Fan (located in Rancho Cucamonga), were each selected for the diversity and the critical character of their habitats. Among the new plant communities studied at the Hidden Ranch site are:
  - Chamise Chaparral
  - Maritime Chaparral-Sagebrush Scrub
  - Purple Sage Scrub
  - Southern Willow Scrub
  - Needlegrass Grassland
  - Coast Live Oak Riparian Woodland
  - Coast Live Oak / Chamise Chaparral Woodland

  Newly studied communities provided by the Etiwanda site include:
  - Alluvial Fan Sage Scrub (Pioneer, Intermediate, and Mature phases)
  - Alluvial Fan Chaparral
  - White Sage Scrub
  - Ceonothus Chaparral
  - Walnut Woodland

  The application of ADAR methodologies to such a diverse range of plant communities allowed the research team to better ascertain the limits and capabilities of ADAR as a mapping tool and some of the conditions that influence ADAR's efficiency.

- To examine the feasibility of detecting changes in habitats over time, based on multi-date ADAR imagery. Research of ADAR's change detection capabilities included developing procedures for locating differences in images from one year to the next, and identifying the relationship of image differences to actual changes on the ground. Image differencing requires co-registration of year-to-year imagery and employs "differencing" procedures. This study examined the relative success of several differencing procedures. The Sycamore Hills site in coastal Orange County, which had been mapped using ADAR in previous years, was the study site for these procedures.

- To describe the relative costs and benefits of using ADAR for mapping and monitoring compared to using conventional mapping methods. Habitat mapping by conventional methods usually involves field surveys conducted by one or more biologists, typically labeling polygons corresponding to plant communities hand drawn over black and white or color aerial photographs. This study identifies conditions when it would be more cost-effective to employ ADAR to map vegetation, the special capabilities of ADAR not available through conventional methods, and the factors that influence the relative costs and benefits of both methods.
- To synthesize the procedures employed in the various tasks and case studies of this research, and to present them in a well-documented format to be used as a Procedures Handbook by SCE's GIAS Laboratory staff. The purpose of the Procedures Handbook is to enable staff to learn and execute the procedures developed through this research for the acquisition, post-processing, and classification of ADAR data in order to produce habitat maps.

The multiple objectives of this research lend a complexity to the project. It is a research project, because of the research required to develop and test refined procedures. It is a demonstrations project in its application of procedures to multiple study sites. It is a comparative analysis that addresses relative benefits of different methodologies. And it is a documentation process designed to transition newly developed procedures into an operational phase.

3.3.3.2 Methods

Habitat Mapping

Three different methods of converting ADAR image frames to image maps were examined to compare their relative cost-effectiveness:

- In-house image processing
- Processing by the vendor
- Processing by third parties

The products of each of these procedures were evaluated for precision (root mean square error) as well as cost and turn-around time in obtaining the product. The use of three different study sites provided the opportunity for case studies to test and evaluate five different in-house methods of in-house image registration and mosaicking. These included:

- Registration and mosaicking to a GIS database
- Registration and mosaicking with GPS coordinates
- Registration and mosaicking with a digital orthophoto quarter quadrangle (DOQQ)
- Registering to existing ADAR image and mosaicking
- Registering and mosaicking using Orthomax software

Habitat mapping at the two new study sites (Hidden Ranch and Etiwanda Alluvial Fan) was performed using the same general methodology previously used for the Sycamore Hills site (Brewster et al., 1998). In the case of Hidden Ranch, ground reference vegetation data was provided in GIS form, prepared under separate contract for SCE by a biological consultant (PCR, 1998). Data for the Etiwanda site was developed for this study by consulting biologist

David Bramlet, based on site visits and both black and white and color aerial photographs converted by researchers into GIS (ArcInfo) format.

Change Detection

Five alternative methods for change detection were tested and evaluated. Change detection procedures were applied to Sycamore Hills image data from 1996 and 1998. The methods examined included:

- Spectral image differencing
- Change vector classification
- NDVI differencing
- Texture differencing
- Post-classification comparison

Comparative Methodologies

Relative costs and benefits of mapping and monitoring using ADAR-based methods compared to conventional methods were ascertained using actual costs derived from our case studies and from the researchers' familiarity with current costs for generic tasks associated with both methods. The important factors that influence relative benefits and costs were described, based on researchers' experience with both conventional and ADAR-based procedures and the quantities of labor, software, hardware, and expertise required to perform specific tasks.

Preparation of Procedures Handbook

Procedures used by researchers to develop image maps from raw ADAR data were carefully documented and described step-by-step so they can be easily followed by SCE GIAS Lab technicians. The Lab staff was provided with the unprocessed ADAR data used in the study, allowing them to apply the procedures themselves and test the Handbook's utility. Their comments and suggestions were based on their interactive, hands-on review, and are incorporated into the Handbook's final version.

3.3.1.3 Outcomes

Habitat Mapping

Results of our comparison of methods indicate that third-party geometric processing of ADAR image data is not currently cost-effective. This is due in part to the rapidly evolving and unperfected state of commercially available image processing technologies. Two different third-party providers were asked to provide processing services. The Hidden Ranch data were provided to ID Vision, Inc., which resulted in a product with low positional accuracy, poor documentation, no header or metadata, and slow turn-around. The cost for this low-quality product was also relatively low. The Sycamore Hills image data were provided to Vexcel Corporation, which also returned a product with slow turn-around and unacceptably low root mean square error.

The five alternative in-house geometric processing procedures were each performed with relative success. The resulting precision varied according to the degree of topographic relief at each of the study sites and according to the quality of available reference data (i.e., GIS database, DOQQ, existing ADAR image). The preferred method depends on three main variables: site characteristics, available georeference data, and mapping objectives. For multi-date monitoring applications, registration to an existing ADAR image map is usually preferable (depending on the quality of the existing image). For other applications, the preferred procedure is to use a high-quality georeference data source such as a DOQQ or Digital Elevation Model (DEM), the latter preferably created from aerial photographic stereo pairs. Orthorectification using GPS points can also achieve a high degree of positional accuracy, although collection of GPS points in the field can be time consuming.

Vegetation Mapping

Classification of habitat types based on ADAR image data was achieved with a satisfactory degree of accuracy for both the Hidden Ranch and Etiwanda sites. At the Hidden Ranch site, differences between the map produced by field biologists (conventional methods) and ADAR classification are mostly attributable to standard sources of error: mapper subjectivity, image displacement, and limited field verification. These errors were committed to some degree by both methods, the magnitude of error and the differences between them accounting for most of the discrepancies.

Because ADAR-based classification is computer-assisted, classification criteria can be codified to allow for more consistent application, potentially reducing subjectivity error. Image displacement error can be more readily corrected using ADAR-based data through application of softcopy photogrammetry and auto-registration. The need for field verification is common to both methods, although ADAR's ability to image inaccessible areas can reduce the need to visually inspect all areas of a study site.

Change Detection

Land cover changes and/or changes in habitat quality were detected by several of the change detection techniques employed. Results of the study demonstrate that important information about habitat condition and change in condition can be derived from ADAR imagery. Changes at the Sycamore Hills site during the two-year period from 1996 to 1998 that were detected from ADAR imagery include:

- Trail widening
- Invasion of poison oak into coastal sage scrub
- Sedimentation in a grassland environment
- Regrowth of vegetation in a previously unvegetated area

These results are significant in establishing the potential value of ADAR imagery as a monitoring tool (as distinct from mapping) for habitat management purposes.

Comparative Costs/Benefits

Comparison of relative benefits of using ADAR technology rather than conventional mapping methods indicated that ADAR has distinct advantages over conventional techniques, which inevitably translates to greater cost-effectiveness. This is especially the case when:

- The need for mapping is repetitive, i.e., a need for frequently refreshed data (three to five years or more)

- The application calls for landscape-level monitoring, particularly monitoring that is specific, purposeful, and related to one or more hypotheses concerning changes in the environment
- The data collection will meet the needs of multiple applications and / or parties
- The resources to be mapped cover an area of medium to large size (at least a few hundred acres)
- The appropriate facilities and personnel are available to perform image processing functions

There are several advantages to integrating ADAR-based mapping within a habitat mapping and monitoring program. First and foremost, the vertical imaging perspective from an airborne platform is the only practical means for conducting a wall-to-wall sample of habitat reserves and reserve systems. This, combined with the capability of synoptically viewing all canopy and exposed substrate features at nearly a single instant in time, is complimentary to the more precise and certain observations made at ground-level with lesser spatial coverage. Many of ADAR's benefits derive from the digital nature of its data, permitting image processing, enhancement, and classification through computer-assisted procedures. The spatially-explicit GIS comparability of the data facilitates its integration with other spatial data sets and use in spatially explicit models. The unclassified nature of raw ADAR data further facilitates its use in multiple applications requiring alternative classification scenarios. Finally, the repeatability of ADAR-related procedures (from data collection through pre-processing and classification) offers the potential for cost-effective monitoring of changes in habitat over time and in the long-term.

3.3.1.4 Recommendations

Results of this study indicate at least three important areas for further research.

- Apply image processing and classification techniques to other habitat types, such as conifer forest, and other woodland and upland plant communities. This would broaden the utility of ADAR and extend its applicability to additional habitat preserves in other geographical regions of California.
- Establish a long-term change detection study to further define and refine ADAR's valuable change detection capabilities. Such a study could readily build on the time-series of ADAR image data initiated through funding for the present research. Research objectives would be to identify categories of long-term changes in habitat that can be detected using ADAR, as well as to augment change detection procedures.
- Identify ADAR image attributes that correspond to habitat quality. This research task relates to a very important function for habitat management, i.e., monitoring changes in quality of habitat (as distinct from changes in habitat type). Sufficient correlation has not been established between on-the-ground characteristics that determine habitat quality and corresponding features detectable on ADAR imagery.

All three of these research topics would significantly advance ADAR's utility in areas that, based on results of this study, ADAR technology offers the most promise for realizing its cost-effective potential.

For more information on this Research Task Component, see Appendix IX.

4.0 RESEARCH PROGRAM OVERVIEW

4.1 Raptor Protection Research

This raptor protection research task had three specific goals:

- Identify the level of raptor mortality occurring in selected raptor concentration areas of SCE's service territory.
- Identify factors that could be influencing raptor perching behavior.
- Identify methods for modifying SCE's existing Raptor Protection Program to make it even more effective in minimizing risk to raptors that utilize our facilities.

4.1.1 What Did We Learn?

In the western United States, with its large expanses of desert, grassland and scrub habitat, and trees, which can serve as natural substrate sites for raptors, are rare. As a result of these conditions, raptors will utilize electric utility facilities, principally transmission and distribution-line structures (this includes wooden and metal poles and lattice steel towers) as perch and nest sites. Additionally, raptors have demonstrated that they will selectively use these poles as perch and nest sites. Raptor selection of these preferred poles is often based on prey availability, habitat types, availability and proximity of natural substrate perch sites (e.g., trees, rock outcrops, etc.), topography, wind direction, etc.

By perching or nesting on these facilities, raptors place themselves in close proximity to energized conductors, which can result in injury or death as a result of electrocutions. As long as there are raptors and power lines, electrocutions will occur. It is impossible to totally prevent raptor electrocutions. However, efforts should and are being expended to minimize the number of electrocutions. It is not feasible, cost-effective, nor necessary to modify all poles to make them raptor-safe. With over 1.4 million poles in SCE's system alone, the cost of modifying all these poles would be extremely high. If expanded to the entire western United States, the cost for modifying all poles could exceed several billion dollars.

The key to this effort, then, is to find a cost-effective approach to identify the preferred poles so that they can be made safe. . Only those poles that are preferred perch sites, located in an area where large numbers of raptors occur, and considered unsafe, need to be modified.

We have learned from this research task that raptor electrocutions appear to be a relatively rare event on SCE's electric distribution and subtransmission line system in the San Jacinto and Owens Valley. Both of these areas are known to support high numbers of raptors during certain times of the year. While these electrocutions are a source of concern for SCE, they do not appear to be biologically significant.

The efforts at identifying preferred perch sites for raptors are more complex. It does not appear that one factor or set of factors can be readily established to identify those poles which raptors prefer to perch on. Pole design seems to have little to do with perching behavior. Factors related to prey obtainment seem to be more important in determining a raptor's selection of perch sites. Prey availability and density will fluctuate from site to site and from year to year, further confounding the ability to identify preferred raptor perch sites.

4.1.2 Benefits of This Task

The information gathered from this research task has been beneficial in that the need to modify large numbers of SCE poles to make them safe for raptors does not appear necessary. This information can be used by other utilities in identifying areas where high raptor concentrations occur, and attempt to quantify more accurately levels of actual mortality.

4.1.3 Improving SCE's Raptor Protection Program

This research has demonstrated that SCE's existing Raptor Protection Program is effective in minimizing impacts to raptors that utilize SCE's facilities for perching and nesting. Can this program be improved upon? The obvious answer is yes. This research has highlighted some weaknesses in the current program that if effectively dealt with will improve the existing program, yielding more effective protection for raptors on SCE's electric and transmission systems. SCE will be evaluating how to utilize this information to improve its current program. This information could be used by other utilities in California or the western United States to see if their program can be improved as well.

4.2 Multiple Species Habitat Conservation Planning

The MSHCP research task consisted of several components. Each of these components involved different endangered species and the conservation of the habitats upon which these species depend. Some of the research was in the development of educational programs (RAMAS® GIS and the MSHCP workshop). These programs offer the potential for facilitating the MSHCP process and reducing the conflicts between endangered species and economic development. Basic research on the natural history and life-table parameters of species like the California gnatcatcher can provide others with basic information needed to effectively manage the species while, once again, minimizing the potential for conflict with sound and well planned economic development. Each of these research components that made up the MSHCP research task are discussed briefly below.

4.2.1 MSHCP Workshop

In addition to the information exchange that occurred between participants at the workshop, results of the workshop are being made available to others so that they may benefit from the significant knowledge and insight of the workshop participants. This will be accomplished by printing a synopsis of the workshop as a chapter in a book on Mediterranean ecosystems being authored by one of the workshop participants, Dr. Peter Bowler. Additionally, individual presentations from the workshop participants are being printed as a special supplement to the journal Environmental Management.

The workshop was helpful in pointing out that development of MSHCPs is no simple process. A cookbook approach must be avoided, as individual species and geographic locations require that the MSHCP be tailored to a specific area and set of circumstances. There was general consensus that more attention needs to be paid to the adequacy of scientific principles in designing, planning, and maintaining preserves established as a result of an MSHCP. Significant attention also needs to be paid to assessing the success of MSHCPs to ensure that they fulfill minimum success criteria. Without monitoring of these success criteria to determine whether the MSHCP is successful, compliance with the Endangered Species Act cannot be achieved, and the overall goals for preserving species embodied in the Act remain unfulfilled.

Recommendations for improving MSHCPs were also identified in the workshop. These recommendations include revising the U.S Fish and Wildlife Service's HCP handbook, as it was generally agreed to be too vague and did not provide adequate guidance. The role and goals that PVAs play in MSHCP development needs to be better identified. A greater diversity of expertise needs to be fully engaged in development of MSHCPs. Traditionally, most expertise involved in planning and developing MSHCPs has involved biologists. With the integration of MSHCPs into the existing developed environment in California, additional expertise is needed in order to determine the role that these external factors exert on MSHCPs and how they should be considered in the planning process.

4.2.2 Population Dynamics, Dispersal and Demography of California Gnatcatchers in Orange County, California (1998 Progress Report)

Acquisition of data on the distribution, ecology, and population dynamics of selected plant and animal species is an important objective of the designing of regional reserves that will ensure the long-term viability of rare and declining habitat types. Development of MSHCP preserves, if successfully designed and implemented, may potentially halt the decline of sensitive species dependent on the habitats being preserved, obviating the need for future listings of species, and avoiding the cumbersome regulatory framework afforded by endangered species laws.

The data acquisition of this project has provided valuable information on the status of the California gnatcatcher, enabling MSHCP planners (in this case working under the auspices of the Natural Community Conservation Planning (NCCP) program) to better understand natural history of this key coastal sage scrub species. By better understanding this species, better decisions can be made on how to plan for future preserves and to more effectively manage existing and future preserves.

4.2.3 Conservation and Management of Coastal Sage Scrub

This research effort is related to the research in 4.2.2. Data gathered from this latter task was used in this research task to update the previously developed California Gnatcatcher model. The model is a spatially explicit, stage-structured, stochastic model of the California gnatcatcher in central and coastal Orange County. At the population level, the model incorporated demographic data on survival, reproduction, and environmental variability for each population inhabiting a habitat patch. The model was implemented in RAMAS® GIS 3.0, which is designed to link landscape data from a geographic information system with a metapopulation model.

As noted in the discussion for the MSHCP workshop, sound science must be employed to help ensure the success of the MSHCP preserve. Without these scientific data, the success of the preserve cannot be ensured. The model developed as part of this research task component will be useful in providing the information necessary to help ensure that existing and future preserves are designed and maintained consistent with best management practices for the species.

4.2.4 RAMAS® Ecological Risk Model for the Desert Tortoise

The desert tortoise continues to be a species of major concern for SCE since so much of our 50,000 mi^2 service territory is within the range of the desert tortoise. Obviously, healthy populations of this species mean that it does not need the critical attention a listed species receives when it becomes listed under state or federal Endangered Species Act. SCE has played an active role in helping to ensure the continued survival of healthy populations of the desert tortoise.

The goal of this research was to build an assessment tool for the evaluation of the population-level risks to the desert tortoise from utility line siting or modification, or from maintenance operations associated with transmission lines within the range of the desert tortoise. Factors effecting the long-term viability of the tortoise were specifically examined.

The analysis suggests that even without additional impacts from transmission line siting or operation and maintenance, tortoise populations will continue to decline throughout most of their range. This ecological risk assessment is a useful management tool that will allow for enhanced monitoring capability of desert tortoise throughout its range, and lead to more effective management of the species.

4.2.5 The Metapopulation Model as an Education Tool: Providing Internet Access to RAMAS® GIS Software

A key to successful implementation of MSHCPs is education, not only sharing information on how to develop MSHCPs, but also scientific information and tools for how to use some of this information. This research task component does this. It has taken a version of the RAMAS® GIS software and made it available on the Internet so that others can access it and see how data can be used, and be aware of the factors considered in species and population management. This task is directly related to the Population Dynamics, Dispersal and Demography of California Gnatcatchers in Orange County, California, Conservation and Management of Coastal Sage Scrub and RAMAS® Ecological Risk Model for the Desert Tortoise research task components as information from these tasks were used as examples on the web site to show how this program works.

4.2.6 Comparison of IUCN and USFWS Classifications of Threatened Species

A determination of the status of species in order to assess the need for protection under state and/or federal law is very important, as this helps to determine the level of protection that a species is afforded. Depending on what a species' legal status is, it can also determine the level of attention that a species receives in its management, and whether special funding will be available to help in the management and conservation of the species. Conversely, if the status of a species is incorrectly assessed, and it does not receive the protection that its condition warrants, a species may be allowed to decline to a point where recovery is much more difficult and expensive to implement. It may even end up past the point where recovery of the species is a reasonable expectation.

The IUCN and the USFWS have developed their own classification schemes to assess the status of various species. If both of these classification schemes were based entirely on good scientific data and principles, one would expect relatively good correspondence between the two schemes. This research task has demonstrated that there is a low correspondence between the USFWS and the IUCN classification schemes. The primary reason for this is the inconsistent use of biological criteria and a heavy reliance on qualitative variables by the USFWS.

This information is important because it indicates that the needs for certain species may be misdirected, with some species receiving protection, management attention, and funding that their condition does not warrant. This information is also helpful within the context of other MSHCP research task components, since the need to set up a preserve and the information relied upon for doing that should be based on the need of the species. Targeting the wrong species in the development of these MSHCP preserves can be counter-productive to the overall success of the preserve, and it can result in a diversion of resources to the wrong species, away from more critical needs of other species.

4.3 California Habitat Evaluation

This research task focused on the use of ADAR to assess critical California habitats. Specifically accomplished in this research task was the development of methodologies for utilizing ADAR to assess and monitor various habitat types in California. The ability to carefully, quickly, and efficiently monitor habitats within MSHCPs is important in the overall management of MSHCP preserves. Without good quality data to assess how management practices are working to affect trends for species, the potential exists that the preserve and the associated species can be mismanaged or not managed effectively.

The ADAR system provides a mechanism for quickly and effectively assessing the status of habitats within a preserve and determining the overall trend, as well as determining whether specific management intervention is required. There is no question as to whether the ADAR system presents specific advantages over more traditional monitoring techniques, because it does. It provides a higher resolution of habitat data, and a more diverse assemblage of data than traditional techniques (e.g., aerial photography with ground verification). However, the question of whether it is cost-effective is unclear. To a large extent, the determination of whether the use of ADAR is worth the extra expense is going to be determined on a case-by-case basis, and will depend on the overall needs for management of the preserve and/or species in question.

4.4 Summary

The Habitat and Species Protection Research program involved a number of research tasks. Some of them, while seeming dissimilar, are in fact very much related. All of the tasks have the ultimate goal of protecting endangered and otherwise sensitive species and their associated habitats in southern California, particularly in relation to the siting and operation and maintenance of electric utility transmission lines. The results of these research tasks have yielded some valuable information and insight as to the effective management of these sensitive resources; not only in SCE’s service territory, but in other portions of California as well. This information is of benefit to SCE and the electric ratepayers of California alike.

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Legal Notice

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Preface

The Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program, managed by the California Energy Commission (Commission), annually awards up to $62 million through the Year 2001 to conduct the most promising public interest energy research by partnering with Research, Development, and Demonstration (RD&D) organizations, including individuals, businesses, utilities, and public or private research institutions.

PIER funding efforts are focused on the following six RD&D program areas:

- Buildings End-Use Energy Efficiency
- Industrial / Agricultural / Water End-Use Energy Efficiency
- Renewable Energy
- Environmentally-Preferred Advanced Generation
- Energy-Related Environmental Research
- Strategic Energy Research.

In 1998, the Commission awarded approximately $17 million to 39 separate transition RD&D projects covering the five PIER subject areas. These projects were selected to preserve the benefits of the most promising ongoing public interest RD&D efforts conducted by investor-owned utilities prior to the onset of electricity restructuring.

What follows is the final report for the Habitat and Species Protection project, one of five projects conducted by Southern California Edison. This project contributes to the Energy-Related Environmental Research program.

For more information on the PIER Program, please visit the Commission's Web site at: http://www.energy.ca.gov/research/index.html or contact the Commission's Publications Unit at 916-654-5200.

Executive Summary

This report presents the results of research performed as part of the Public Interest Energy Research (PIER) program funded by the California Energy Commission. The Habitat and Species Protection Research Program involves three components that seek to minimize the impacts on habitats and species from the siting, operation, and maintenance of utility transmission and distribution systems. These three components are:

- Raptor Protection Research
- Multiple Species Habitat Conservation
- California Habitat Evaluation

The Habitat and Species Protection Research program involved a number of research tasks. Some of them, while in some cases seemingly dissimilar and not related, are in fact very much related. All of the tasks have the ultimate goal of protecting endangered and otherwise sensitive species and their associated habitat in Southern California, particularly in relation to the siting, operation and maintenance of electric utility transmission lines.

Raptor Protection Research

Raptors are defined as birds of prey, such as hawks and owls. Raptor mortality due to interactions with power lines is well documented in scientific literature and in utility industry publications. Raptors are protected under several state and federal regulations.

Objectives:

- Characterize and quantify raptor use of power poles and towers as perches by surveying regions supporting particularly large concentrations of raptors during the time of year when they are most abundant.
- Search locations beneath the poles in an attempt to quantify raptor fatalities due to electrocution.
- Use this information to determine the relative risk to raptors associated with perching on power poles, as well as to determine factors influencing raptor perch selection. The results will allow poles that are likely perch sites to be made safer for raptor use.
- Evaluate the reporting procedures used in Southern California Edison’s (SCE) current Raptor Protection Program in an attempt to improve this already effective program and provide additional protection to raptors.

Outcomes:

This component of the research documented actual levels of raptor use and mortality occurring on utility power line systems and provided recommendations to reduce this mortality using methods that are both cost-effective and likely to improve system reliability. These methods may be applied to power line systems not only within Southern California Edison's (SCE’s) service territory, but throughout California to lower mortality of raptors statewide.

Conclusions:

The results of this research indicate that raptor electrocutions on SCE’s system are not as frequent as once thought. They also appear to be episodic in nature. By combining data and findings from the research performed in the Owens Valley and the San Jacinto Valley, SCE is much closer to a system-wide proactive approach to developing solutions for minimizing raptor electrocutions and overall compliance with agency regulations.

Recommendations:

- Keep the SCE database of raptor electrocutions current as new fatalities occur. Use the updated information to modify preventative measures as needed.
- Focus future efforts on the development of predictive models that both identify regions, lines, or specific poles with a high probability of raptor use by vulnerable species, and identify pole line configurations that have documented raptor electrocutions associated with them.
- Use this pre-treatment versus post-treatment fatality survey data to move toward reducing electrocutions.
- Take steps to improve SCE's Raptor Protection Program by ensuring that raptor electrocutions at SCE facilities are not under-reported.

Multiple Species Habitat Conservation Plan

For years, the development of Multiple Species Habitat Conservation Plans (MSHCPs) has been identified as a preferred mechanism for dealing with the innumerable conflicts between endangered species and sustainable economic development. With over 500 state and federally-listed species within California, the potential for conflict between these species and proposed economic development, even ongoing activities for infrastructure maintenance, is very high. One of the ways that SCE believes that this conflict can be reduced is to have MSHCPs in place that provide a mechanism for protecting multiple species and their associated habitats, that also allow for development to proceed in a controlled and predictable pattern.

The MSHCP research component directly addresses land use issues as they relate to sensitive species. Through research designed to facilitate the development of multiple species habitat reserves, this component will aid in providing protection for endangered species through an ecosystem approach at lower cost and with less conflict than the traditional species-by-species approach.

Objectives:

- Organize and conduct a workshop dedicated to facilitating the development of MSHCPs in California. Publish the results to allow others involved in developing MSHCPs to benefit from the collective knowledge and experience of the workshop participants.
- Collect data on factors affecting patterns of dispersal by California gnatcatchers. Determine what factors influence annual variation in California gnatcatcher reproductive success, survivorship, and territory size, and what the implications are for research aimed at monitoring populations of these species.
- Update the California Gnatcatcher model that was developed and published in 1997, taking advantage of the two years' worth of new data that has become available since then. Apply information about the gnatcatcher's interaction with its habitat to determine

the best method to maintain management and conservation of coastal sage scrub habitats.

- Build an assessment tool to examine potential population-level risks to the desert tortoise that would result from constructing and modifying transmission lines in the tortoise habitat.
- Develop an interactive web site that allows users to run a demo of RAMAS® GIS 3.0 software.
- Evaluate the USFWS listing protocol by comparing 60 species' risk classifications with those in a system used by the World Conservation Union.

Outcomes:

- From the workshop, recommendations were developed for improving MSHCPs. Publications of the outcomes enhanced distribution of the recommendations.
- In the coastal Orange County study sites, populations of California gnatcatchers were essentially stable from 1993 – 1998. Comparisons of survivorship estimates between Orange County and Palos Verdes failed to detect any significant difference between the two localities for adults of either sex. The same was true of juvenile dispersal distances.
- With the medium parameter estimates, the updated gnatcatcher model predicted a substantial decline, but a low risk of extinction of the gnatcatcher populations. The risk of falling below the metapopulation threshold of 30 females within 50 years was about 10%. Although the extinction risk was low, the risk of a substantial decline was high.
- The RAMAS® Ecological Risk Model makes a number of predictions. Fragmentation, habitat loss (reduction in carrying capacity) and raven predation increase the risk of a decline in abundance for the tortoise metapopulation. The results of this model suggest that the potential impacts of transmission line siting and maintenance were dependent on which populations were affected, but the effects were usually moderate. This finding supports empirical studies indicating that these populations are experiencing a large decline in abundance.
- The RAMAS® GIS website contains three sections that are launched from the main page (*index.htm*).
  - Part 1: Conservation and Management of Coastal Sage Scrub
  - Part 2: Desert Tortoise Metapopulation Dynamics (Phase II)
  - Part 3: The metapopulation model as an educational tool
- Agreement between the USFWS and the IUCN selection criteria were compared for 60 native California species. The listing status of 19 of them did not fit into corresponding categories of the IUCN and the USFWS. Eight species were listed in a higher endangerment category by the USFWS, while 11 were either not listed (9) or listed in a lower threat category (2) by USFWS.

Conclusions:

- . The information gathered at the workshop will be invaluable both in the siting of new facilities and in the management of existing facilities and rights-of-way that traverse multiple species habitat preserves.

- Because of the major time investment involved in establishing uniquely-banded populations of known-age, known-natal area birds, and the value of such a study population in addressing regional conservation issues, the Palos Verdes / Orange County (coastal) project represents a critical research element contributing to the State of California's NCCP efforts.
- It would be inappropriate to use the results of the updated gnatcatcher model to conclude that gnatcatcher populations in Central / Coastal Orange County are either threatened by extinction or secure from such a threat. There is too much uncertainty to predict with confidence what the population size will be in 50 years, or what the risk of extinction might be. Despite this uncertainty, the model can potentially have practical application in several areas. These applications also indicate future research directions.
- The RAMAS® GIS web site will serve as an excellent educational tool. It also highlights SCE's commitment to environmental research and conservation of native species.
- The inconsistent use of biological criteria and heavy reliance on qualitative variables by the USFWS result in a low correspondence with the IUCN system and with its own "degree of threat" ranking under the recovery priority listing system. The low correspondence with the IUCN categories was found in spite of the assumption that each USFWS category corresponds to two IUCN categories.
- The IUCN listing system has several advantages over the USFWS protocol. The IUCN listing process was developed under wide consultation and is recognized internationally by the public and scientific community.

Recommendations:

- Follow the recommendations determined at the workshop, some of which included:

  For the FWS:

  – Revise the HCP handbook to clarify the standards for acceptable data in plan development.

  – Provide further clarification and standardization. Establish standards for how all material used to build an HCP are referenced. Clarify the issue of "species-based" vs. "ecosystem-based" plans. Better explain the role of an HCP in recovering a species. Provide clear guidance on what constitutes acceptable mitigation from the standpoint of endangered species policy.

  – Initiate project management, especially a detailed front-end scoping of a plan.

  – Develop new funding mechanisms to increase the number of personnel available for assistance, and to expend the resources necessary to establish firm guidance for those people.

  – View lands to be developed as research tools, so that ecological experiments can be performed prior to habitat destruction.

  For creators of HCPs:

  – Ensure that plans are complete. Define the uncertainty associated with each major data set, and state specific goals and criteria for meeting them.

  - Place greater emphasis on stakeholders, including agencies, at all stages of the planning process. Provide a basic understanding of project financing.
  - Improve the planning process. Utilize planners possessing a wider range of skills, begin the planning using best land management practices, and incorporate independent peer review at each major stage of the process.
  - Each HCP should contribute to the overall understanding of ecological processes driving the HCP concept. That is, projects should be planned so that successes and failures in strategy and implementation can be documented and future projects can benefit from the knowledge.
- Conduct further fieldwork to narrow down uncertainties in the PVA model parameters, making model predictions more accurate and reliable.
- Expand the PVA model to include the populations of California Gnatcatcher in other areas.
- Use metapopulation modeling to provide guidance in reserve design, by identifying the ecological and economic consequences of each design configuration.
- Assess the effects of management actions and human impact in terms of model parameters, to determine potential consequences and rank alternative actions.
- Express the worth, in conservation terms, of a location by using the habitat-based metapopulation modeling approach on a list of selected species. Create habitat suitability maps and metapopulation models for all species in the list. Combine each of the individual habitat suitability maps into a single aggregate map.
- Conduct additional empirical studies of the tortoise, especially in the area of density dependence and predation.
- Create a new decision-making process for selection of species to protect, similar in structure to the IUCN system but modified to satisfy the specifications of the ESA.

California Habitat Evaluation

The California Habitat Evaluation research component developed operational protocols to characterize and monitor critical habitats in California using high-resolution airborne multi-spectral imagery obtained using a system called Advanced Digital Airborne Registration (ADAR). This research supported the establishment of multiple species reserves with the highest habitat values, and will aid in more timely management responses to changes in the environment.

The availability of ADAR technology to support management of preserves will not only assist SCE, as a permittee with coastal sage scrub habitat in Natural Communities Conservation Planning (NCCP) preserves, but can also assist other NCCP participants (such as San Diego Gas & Electric) as well as the regulatory public agencies (California Department of Fish & Game and USFWS). Mapping and monitoring tools also have the potential to serve conservation needs within California and beyond that are outside the regulatory purview of the NCCP. As multi-species and habitat-based conservation programs proliferate in California, the demand for cost-effective habitat management tools will increase. As a rapid, efficient method for collection of digital, landscape-level data, ADAR has the potential to provide the real-time data necessary to drive monitoring and management tools such as RAMAS® GIS 3.0 and other metapopulation models. Development of mapping and monitoring tools through this research lays the groundwork for a wide range of capabilities that comprise the toolbox for managing California's legacy of habitat preserves.

Objectives:

- Enlarge the mapping capabilities of ADAR methodologies to include numerous habitat types not previously established within the technology's repertoire, in order to better understand the limits and capabilities of ADAR as a mapping tool.
- Examine the feasibility of detecting changes in habitats over time, based on multi-date ADAR imagery.
- Describe the relative costs and benefits of using ADAR for mapping and monitoring compared to using conventional mapping methods.
- Synthesize the procedures employed in the various tasks and case studies of this research, and present them in a well-documented format to be used as a Procedures Handbook by SCE's GIAS Laboratory staff.

Outcomes:

During this task, the applications of the ADAR tool were expanded to other habitat types and tested, and work was continued on existing areas.

- Classification of habitat types based on ADAR image data was achieved with a satisfactory degree of accuracy for both the Hidden Ranch and Etiwanda sites. At the Hidden Ranch site, differences between the map produced by field biologists (conventional methods) and ADAR classification are mostly attributable to standard sources of error: mapper subjectivity, image displacement, and limited field verification.
- Because ADAR-based classification is computer-assisted, classification criteria can be codified to allow for more consistent application, potentially reducing subjectivity error.
- Land cover changes and / or changes in habitat quality were detected by several of the change detection techniques employed. Results of the study demonstrate that important information about habitat condition and change in condition can be derived from ADAR imagery.

Conclusions:

- Results of our comparison of methods indicate that third-party geometric processing of ADAR image data is not currently cost-effective. This is due in part to the rapidly evolving and unperfected state of commercially available image processing technologies.
- Comparison of relative benefits of using ADAR technology rather than conventional mapping methods indicated that ADAR has distinct advantages over conventional techniques, which inevitably translates to greater cost-effectiveness.

Recommendations:

Results of this study indicate at least three important areas for further research.

- Apply image processing and classification techniques to other habitat types, such as conifer forest, and other woodland and upland plant communities.
- Establish a long-term change detection study to further define and refine ADAR's valuable change detection capabilities.
- Identify ADAR image attributes that correspond to habitat quality.

All three of these research topics would significantly advance ADAR's utility in areas that, based on results of this study, ADAR technology offers the most promise for realizing its cost-effective potential.

Abstract

Southern California Edison undertook research with California Energy Commission funds as part of the Commission's PIER (Public Interest Energy Research) research program.

This research, entitled Habitat and Species Protection, involved three main components that seek to minimize the impacts on habitats and species from the siting operation and maintenance of utility transmission and distribution systems. The three main components are: 1) Raptor mortality studies in southern California; 2) Multiple species habitat protection; and, 3) California habitat evaluation.

The research on raptor mortality examined the interactions of raptors and power lines within two raptor concentration areas within SCE's service territory. Similar techniques were used in both study areas to examine the level of raptor mortality in each area. This research demonstrated that mortality does occur, but at very low levels. In the San Jacinto Valley study area, a total of 7 dead raptors were found, only two of which could be attributed to electrocution. In the Owens Valley study area, 11 raptors were found, 6 of which were known or suspected electrocutions. These data yield a mortality rate of 0.00010 electrocutions per month per surveyed pole in the San Jacinto Valley, and 0.00048 electrocutions per month per surveyed pole in the Owens Valley. These are extremely low numbers, especially when compared to what other western utilities have experienced.

The multiple species habitat conservation protection (MSHCP) research component consisted of a number of tasks designed to enhance species conservation by promoting the use of multiple species habitat conservation planning, education and management of multiple species preserves. These tasks consisted of holding a workshop on MSHCP planning in order to facilitate the process; furthering the data base on the California gnatcatcher, a primary species for protection of the coastal sage scrub community in southern California; ecological risk modeling of the desert tortoise; using the metapopulation tools developed for the desert tortoise and the gnatcatcher as an educational tool by providing access to RAMAS® GIS 3.0 software; and an examination of correspondence between the World Conservation Union's (IUCN) and U.S. Fish and Wildlife Service's classification of species at risk.. This research has resulted in research reports designed to enhance development of multiple habitat preserves, aid in their management and will assist in the management of existing and future facilities which traverse many of the current and proposed multiple species habitat preserves.

The California habitat evaluation research component develops operational protocols to characterize and monitor critical habitats in California using high resolution airborne multi-spectral imagery using a system called Advanced Digital Airborne Registration (ADAR). This research will support the development and management of multiple species habitat preserves by closely monitoring small changes in measured environmental variables to detect how effective certain management prescriptions are performing and how the habitat is responding to biotic and abiotic variables. This research has established the value of ADAR technology to support management of preserves and species in southern California.

1.0 Introduction

1.1 Background to California Energy Commission Public Interest Energy Research Program

The Public Interest Energy Research (PIER) Program was developed by the California Energy Commission (CEC) in response to Assembly Bill (AB) 1890, which provided authority for a fundamental restructuring of California's electric services industry. As a result of the implementation of AB 1890, approximately $61.8 million is transferred from the California Public Utilities Commission (CPUC) annually to the CEC to administer specific Research Design and Development projects.

The overall mission of the PIER program is to "improve the quality of life for California citizens by providing environmentally sound, safe, reliable, and affordable energy services and products." In 1997, Senate Bill 90 was enacted into law and included five subject areas for expenditure of funds under the PIER program. One of these five criteria is "Energy Related Environmental Enhancement" under which Southern California Edison's (SCE's) Habitat and Species Protection Project was funded.

Three specific research tasks were identified in as part of the Habitat and Species Protection research program. These three research tasks included Raptor Protection Research, Multiple Species Habitat Conservation Planning (MSHCP), and California Habitat Evaluation. Each of these research tasks is described in more detail later in this section and in other sections of this report.

1.2 SCE's Research Needs - A Historical Perspective

SCE operates and maintains a complex array of distribution and transmission line facilities in central and southern California. Within this 50,000 square mile service territory, there are more than 100 rare, threatened, or endangered species, and several hundred species of concern. Issues involving the effects and potential effects of electric facilities on sensitive species and their habitat are currently being addressed by SCE. For example, SCE has maintained a very active endangered species protection program for over 10 years. This program, SCE's Endangered Species Alert Program (ESAP) is an award-winning program designed to minimize and / or avoid impacts to legally protected species and other sensitive biological resources.

The main component of ESAP is a manual that contains information on all listed species within SCE's service territory. SCE planners and maintenance people review this manual prior to performing any ground disturbing activity to determine if any legally protected species potentially occur in the area. If it is determined that they do, then an SCE biologist is called in to review the proposed activity and to find methods for accomplishing the necessary work without impacting the sensitive resource. This program has worked well to minimize or avoid SCE's impacts on sensitive biological resources and thereby maintain SCE's compliance with state and federal law. The ESAP manual is in its 3rd edition, and has recently been made available on SCE's intranet, so anyone in SCE can access the manual via SCE's Environmental Affairs home page.

Other programs that SCE has undertaken in support of SCE's endangered species protection program include:

- Preparing special maps showing the distribution of listed species in relation to our power lines
- Financially supporting Multiple Species Habitat Conservation Planning in Riverside County
- Researching the desert tortoise and other listed or sensitive species (island fox, bald eagle, California gnatcatcher, etc.)

Most recently, the SCE developed and implemented a program called Archaeological and Biological Resource Application (ABRA), which allows users to view a USGS quadrangle map, with SCE transmission lines displayed. The user can identify an area where ground-disturbing activities are planned by clicking on a portion of the map. The ABRA program will then identify if there are biological or archaeological sensitivities in the area by displaying a dialogue box. If sensitivities are known or expected to occur in the area, it will identify whether the sensitivity is biological and / or archaeological in nature. By clicking on the sensitivity category, a new dialogue box will appear identifying the exact nature of the sensitivity, and provide information on avoiding the sensitivity or provide direction on contacting Environmental Affairs. If the sensitivity is biological in nature, it will provide a list of species or natural communities known or expected to occur at the given location. If the species is a listed species, one can click on the species name and it will open the corresponding page from SCE's ESAP manual, providing the reader with the most current information available about the subject species.

SCE facilities occur in regions supporting raptor concentrations that vary throughout the year. During winter, raptors concentrate in portions of SCE's service territory, specifically the San Jacinto Valley in Riverside County and the Owens Valley in Inyo County. In these mostly treeless environments, raptors will utilize SCE's power line poles and towers for perching and roosting. In many cases, raptors also nest on these facilities. High use of SCE power lines can significantly increase the potential for electrocution-caused mortality.

SCE has maintained a Raptor Protection Program since 1986. This program consists of educating field personnel on procedures to follow in dealing with raptor mortality and how to protect active nests. The program works on the "preferred pole" concept. That is, raptors are known to display preferences in which poles they perch on. Their selection is often based on a variety of factors, including prey availability, habitat diversity, topography, prevailing wind direction, etc. During the fall of 1997, SCE conducted research to determine whether a significant raptor electrocution problem exists in the San Jacinto Valley. After extensive field work, no raptor mortality or power outages were recorded due to electrocutions. The results of the 1997 research indicated that the rate of raptor mortality from electrocution is significantly lower than previously reported by the California Department of Fish and Game. The Raptor Protection Research component of this document is a continuation of work that SCE initiated in 1997. In addition to continuing and expanding on this work, similar research was conducted in the northern Owens Valley region.

1.3 SCE's Goals and Objectives

The Habitat and Species Protection Program includes three components that seek to minimize the impact on habitats and species from the siting, operation, and maintenance of utility transmission and distribution systems. These three components are:

- Raptor Protection Research
- Multiple Species Habitat Conservation
- California Habitat Evaluation

Raptor Protection Research

The Raptor Protection Research component is designed to quantify the severity of raptor electrocutions occurring on power poles and/or towers. It documents actual levels of raptor use and mortality occurring on utility power line systems and provides recommendations to reduce this mortality using methods that are both cost-effective and likely to improve system reliability. These methods may be applied to power line systems not only within SCE's service territory, but throughout California to reduce mortality to raptors statewide.

Raptor mortality due to interactions with powerlines is well documented in scientific literature and in utility industry publications. Raptors are protected pursuant to several state and federal regulations. These include the state and federal Endangered Species Acts, the Bald Eagle Protection Act, California Department of Fish and Game Code and the federal Migratory Bird Treaty Act. Direct and indirect application of various elements of these laws require SCE to provide prudent management measures to minimize and avoid impacts to these protected species. By combining data and findings from the Owens Valley and the San Jacinto Valley, SCE is much closer to a system-wide pro-active approach and solutions to minimizing raptor electrocutions and overall compliance with agency regulations.

Multiple Species Habitat Conservation Plan (MSHCP)

The MSHCP research task directly addresses land use issues as they relate to sensitive species. Through research designed to facilitate the development of multiple species habitat reserves, this component will aid in providing protection for endangered species through an ecosystem approach at lower cost and with less conflict than the traditional species-by-species approach. This information will be invaluable both in the siting of new facilities and the management of existing facilities and rights-of-way which traverse multiple species habitat preserves.

California Habitat Evaluation

The California Habitat Evaluation component develops operational protocols to characterize and monitor critical habitats in California using high-resolution airborne multi-spectral imagery obtained using a system called Advanced Digital Airborne Registration (ADAR). This research supported the establishment of multiple species reserves with the highest habitat values, and will aid in more timely management responses to changes in the environment.

1.4 Report Organization

This report is organized first with some introductory material (Sections 1 and 2), providing some background on the research topic, and SCE's interest, history, and involvement with these issues. Goals and objectives of the overall research program and individual research tasks are also identified.

Following these introductory sections, a summary of each research task and research component of each task is provided in Section 3. These summaries represent a distillation of the individual consultant reports that are attached as appendices to this report.

Section 4 provides an overview of the research performed, summarizing the information learned from this overall research project and integrates all individual research tasks and research components. Section 5 lists references used in preparing this material.

Individual consultant reports are bound separately and attached as appendices to this report.

2.0 Approach

2.1 PIER Funding

SCE addresses important research needs in its "Habitat and Species Protection Program," one of the projects funded under contract number 500-97-012 issued on December 28, 1997. The Program consists of three components: Raptor Protection Research, Multiple Species Habitat Conservation, and California Habitat Evaluation. Although some of the research conducted for this Program is habitat- or species-specific within SCE's service territory, the methodologies and databases developed have regional and statewide applications.

2.2 SCE's Management and Quality Control

SCE was the primary investigator for this research, although most of the work was performed by qualified consultants working under SCE's guidance. In addition to laying out the work scope in concert with the individual consultants, SCE made adjustments as necessary to ensure that work was directed towards providing greatest benefit to the environment and the electric utility consumer. SCE has worked closely with the individual consultants to ensure that the final reports reflect this commitment to the environment and to the electric ratepayers of California.

In addition to overall direction in establishing the scope and direction of the research project, SCE oversaw the ongoing work, and worked directly with individual consultants to answer questions and provide guidance and direction. .

2.3 Selection of Contractors (Consultants)

A team of consultants was already working on SCE research projects specifically related to this research. Hence, it made sense to maintain the same consultants for the California Energy Commission PIER funded research in order to minimize costs and maximize use of previously gathered information. Consultants originally selected for this work, prior to PIER funding, were preeminently qualified to undertake this research. A discussion of the qualifications for each of the consultants follows:

- **BioReource Consultants** - This organization is headed by Carl Thelander. Mr. Thelander has over 20 years experience providing biological consulting services throughout the western United States, especially to major electric utilities in California. Carl has specific expertise with raptors, endangered species, and ecological systems modeling. Because of his vast experience as a biological consultant, Carl also has a vast network of contacts that are involved in protecting and managing biological resource issues here in California. This experience made Carl Thelander and BioResource Consultants ideal candidates to manage the Raptor Protection Research task, and the MSHCP Workshop component of the MSHCP research task. For this latter task, Carl solicited the assistance of Dr. Mike Morrison, Adjunct Professor at California State University at Sacramento. Dr. Morrison's expertise is experimental design, HCP development, and statistical analysis. Dr. Morrison was the principal coordinator and manager of the MSHCP Workshop held at SCE offices in March, 1999. Dr. Morrison has also been involved in the Raptor Protection Research task, helping establish sampling design and statistical analysis of data.

- **Applied Biomathematics -** Applied Biomathematics has been under contract to SCE and the Electric Power Research Institute (EPRI) for a number of years. Their expertise is in mathematical modeling of populations and population viability analysis (PVA). Key members of their staff that have participated in this research have been Dr. Lev Ginsburg, Dr. Resit Akçakaya, and Dr. Karen Root. Applied Biomathematics has developed the well-known and widely distributed RAMAS® software, which is principally a program for performing PVAs of various species. Dr. Karen Root was responsible for *the Desert Tortoise Metapopulation Dynamics* and *The Metapopulation Model as an Educational Tool: Providing Internet Access to RAMAS®-GIS Software* research components of the MSHCP research task. Dr. Resit Akçakaya was primarily responsible for the *Conservation and Management of Coastal Sage Scrub* and the *Correspondence Between IUCN and USFWS Classifications for Threatened Species* research components of the MSHCP research task.
- **Dr. Peter Bowler -** Dr. Bowler is a professor at the University of California, Irvine. His expertise is in habitat dynamics and restoration and coastal sage scrub ecosystems. Dr. Bowler has been involved in long-range research on the California gnatcatcher, including several years for SCE. Dr. Bowler was responsible for the Monitoring and Management-related Research on California Gnatcatcher and Cactus Wren Subpopulations in the San Joaquin Hills and Palos Verdes. Dr. Bowler collaborated on the research with Dr. Jonathan Atwood, considered by many to be the preeminent expert on the California gnatcatcher.
- **Ed Almanza, SuperPark Project -** Ed Almanza has been involved in ADAR (Airborne Data Acquisition and Registration) for a number of years, pioneering the development and implementation of this relatively new data acquisition system. Mr. Almanza has also worked for a number of years on coastal sage scrub and NCCP issues, particularly in Orange County.

2.4 Schedule of Work

Work on the individual research tasks was initiated in 1998. For that work involving field studies, work was performed at the appropriate time of the year to ensure adequate data collection.

2.5 Preparation of Deliverables

Consultants prepared reports of their findings as work progressed. These reports can be found as appendices to this document.

2.6 Integration by SCE

Overall direction and guidance on the Habitat and Species Protection Research Program was provided by SCE. All of these research tasks comprising this research program have in common a relationship to power line siting and operation and maintenance activities, and the effect that these facilities have on sensitive biological resources that can be found within the right-of-ways for these facilities. Additionally, the research tasks and components have the ability to extend beyond the electric utility rights-of-ways, and have potential application and benefit for others in California.

3.0 Research Results

3.1 Raptor Protection Research

3.1.1 Assessing Power Line Use and Electrocutions by Raptors

3.1.1.1 Background

SCE operates electrical generation, transmission, and distribution facilities in a diverse service area that extends from rural / undeveloped Fresno / Mono counties in the Sierra Nevada to urban Los Angeles / Orange counties on the south, and to Arizona and Nevada in the east. A majority of this 50,000-square-mile service area is comprised of rural agriculture lands or natural vegetation. These areas support a variety of wildlife species, including numerous raptors. Raptors are defined as birds of prey, such as hawks and owls.

Utility power poles attract raptors for numerous reasons (Bevanger 1994). Primarily, they provide perches from which nocturnal and diurnal species can hunt, feed, and sometimes nest. While raptors benefit from the distribution and number of the power poles, these artificial perches have hazards in the form of energized components or hardware. . When raptors make contact with these energized components, they are sometimes killed or injured by electrocution (Bensen 1981; Kochert and Olendorff 1999; Olendorff et al. 1981; Williams and Colson 1989; Miller et al. 1975). Williams and Colson (1989) identify 17 species of raptors that have been electrocuted in the western United States.

Raptor protection measures are often incorporated into the permitting and licensing requirements placed upon the utility industry for new power line projects. In addition, SCE has implemented its own Raptor Protection Program. This program is designed to identify problem areas or poles so that appropriate modifications can be made, and to monitor raptor electrocutions system-wide. Poles associated with electrocution events, or suspected of causing them, are modified to make them safer and to discourage raptors from perching on them.

The causes of raptor electrocution are well documented (APLIC 1996). The size of the bird is by far the most crucial factor in certain species' being more prone to electrocutions. Larger birds are more likely to span conductors with outstretched wings or other body parts. Most electrocution events occur on distribution lines rather than high-voltage transmission lines (Olendorff et al. 1981). The frequency of electrocutions is highest in areas where raptors congregate in response to prey availability.

3.1.1.2 Objectives

In the SCE service area, several regions support particularly large concentrations of raptors, especially during the fall and winter months. The purpose of this research project was to characterize and quantify raptor use in two of these raptor concentration areas. Concurrent with the raptor use surveys, raptor fatality searches were conducted under the same power poles. By combining the results of these surveys, the relative level of risk to raptors associated with perching on power poles could be determined in these two regions, and factors influencing raptor perch selection could be assessed.

One additional (non-survey) study objective was to evaluate the reporting procedures used in SCE's Raptor Protection Program. To do this, the raptor fatalities encountered in the field were compared with data reported within SCE's computer database of power outages and causes. Also, interviews were conducted with maintenance personnel responsible for reporting and investigating raptor electrocutions and other system outages in each of the study areas. The goal of this latter effort was to take SCE's already effective Raptor Protection Program and improve it so that it would be more effective in providing protection to raptors.

3.1.1.3 Methods

Study Areas

In the San Jacinto Valley, Riverside County, 35.1 miles of roadside survey routes were established. A total of 1,802 power poles were represented in these surveys. In the Owens Valley, Inyo County, 72.8 miles of roadside survey routes were established. A total of 1,679 power poles were represented.

In both study areas, survey routes were selected for their proximity and access to distribution power lines that traverse the areas. This included roads ranging from highways to dirt maintenance roads, or segments where walking was required. The length of the routes was primarily determined by the number of poles that could be thoroughly surveyed on foot for dead raptors no less than twice per month.

Survey Methodology

Initially, each study area was visited to establish the survey routes and define the pole locations to be included in the surveys. Once the routes were established, the same poles were surveyed during each sampling event. All poles included in the surveys were inventoried and characterized by type (approximately 25 configurations represented) based on their line and insulator installations. Each type was assigned an alpha-numeric code for use on data collection forms.

The survey routes were subdivided into numerous segments and assigned numeric codes that coincided with road intersections, changes in power line direction, or some other obvious landmark or physical feature. Within each segment, each power pole was assigned a unique identification number. This segmentation helped maintain accuracy in assigning pole numbers during data entry and in navigating the complex survey route.

While the approach to the research in each of the two study areas was generally the same, the field effort applied in the San Jacinto Valley was more intensive than that applied in the Owens Valley. The San Jacinto Valley research was designed and underway by October 1997. The first survey period was from October 1997 through March 1998. The second survey period was from November 1998 through March 1999. The Owens Valley research was initiated by BioResource Consultants from February-April, 1998. SCE funded the second survey period, from November, 1998 to March 1999.

Roadside raptor counts are a widely used method of determining species occurrence and relative abundance. The data collection was limited to raptors perched on power poles. Flying raptors were not included in the counts. In the first survey period in each study area, intensive roadside raptor counts were conducted to quantify raptor use of power poles. These surveys were conducted independently from the fatality searches.

In the second survey period in each study area, intensive roadside raptor counts were not conducted. Instead, only those raptors observed on power poles were recorded while conducting continuing fatality searches. A priority was placed on surveying for electrocuted raptors, since this was the most time-consuming task, and the primary focus of the research effort. . Therefore, the raptor-power pole use results for the two samples in each study area were not meant to be directly comparable.

Fatality searches required a combination of driving slowly and walking along the survey routes to visit each power pole. The raptor fatality survey methods used in all study periods and in both study areas remained comparable throughout the study.

Electrocuted raptors are typically found at the base of power poles. They die immediately and fall to the ground. Therefore, a minimum radius of five meters around each pole was intensively searched for the presence / absence of dead birds. In most areas, a much larger area was easily surveyed, since vegetation was usually sparse or non-existent.

When evidence of a bird was present, a standardized set of data entries was recorded onto a field form. A field inspection was conducted to determine the cause of death. When whole carcasses were found, they were taken to a qualified veterinarian for necropsy.

Raptor Mortality Surveys

The fieldwork was scheduled to ensure that every power pole was surveyed for dead raptors twice per month. The San Jacinto Valley routes were surveyed twice per month in October 1997 through February 1998. One survey was completed in March 1998. The Owens Valley routes were surveyed twice per month in February and March 1998 and once in April 1998. These routes were surveyed twice per month in November 1998- February 1999. A single (final) survey was completed in March 1999.

Raptor Use Surveys

Each raptor use survey consisted of one (sometimes two) observer(s) driving along the predetermined route(s). . Generally, roads were traveled at a safe rate of speed suitable for observing and identifying to species any raptor perched on a power pole. Every raptor (except American kestrels and common ravens) observed perching on a power pole was recorded. The pace of the survey was dictated by the frequency of raptors along the route. The observers stopped when necessary to ensure a complete census of every pole. As needed, a spotting scope was used to make accurate species identifications.

All surveys began in the morning, usually by 7:30, and ended before 11:00 a.m. to maximize the number of observations of perched raptors. Starting points along the survey routes varied randomly. The sampling schedule was maintained regardless of weather conditions.

Each raptor observed perching was recorded as a single event. All data were recorded in the field using standardized forms. These data were then transferred to electronic databases using Microsoft Excel software. The raptor use form included data fields for date, route, observation number (sequential per day), species observed, survey segment, pole number, pole type, location on pole, predominant habitat type adjacent to the pole, weather, wind, and other comments.

3.1.1.4 Outcomes

In the San Jacinto study area, from October 6, 1998 to March 15, 1999, 92 raptor use surveys were completed: 56 on the east route and 36 on the south route. The second set of surveys occurred between November 1, 1998 and March 15, 1999. These surveys were conducted incidental to the fatality searches, which progressed at a rate of two complete surveys per route per month.

In the Owens Valley study area, from February 1, 1998 to April 16, 1998, 36 raptor use surveys were conducted. The study area was divided into four routes (seven at Chalfant, 15 at Laws, 10 at Round Valley, and four at Mill Pond. The second set of surveys was conducted incidental to fatality searches conducted between November 1, 1998 and March 15, 1999. No record was kept of incidental raptor observations during the initial November surveys.

Raptor Fatalities

Twelve raptor fatalities were found in the Owens Valley study area. Of these, it is believed that as many as seven may have died as a result of shooting. All of these occurred in the Five Bridges area north of Bishop. Fatality event numbers 1 through 5 and 10 through 12 were all killed during the survey period. Fatality event numbers 6 through 9 appeared to be old kills when they were discovered. The cause of death could not be determined, and according to a CDFG biologist, the area has had problems with raptor shootings. Therefore, four of the 12 fatality events were excluded from analysis of risk due to electrocution during the period of the surveys.

Seven raptor fatalities were found in the San Jacinto Valley study area. Fatality event numbers 1 and 2 were old carcasses of birds that died before the surveys began. Fatality event numbers 3 and 4 were unusual in that both birds were found together lying on their backs. A necropsy revealed no known cause of death. There was no evidence of electrocution. Fatality event number 5 had scorched wing feathers and was therefore considered likely to have been electrocuted. Fatality event number 6 was found fresh but the necropsy revealed no known cause of death. Fatality event number 7 was an old carcass (bones only) that was uncovered by recent rains. Therefore, only one verified electrocution occurred in the study area during the course of the surveys. It is likely, however, that some of the others found were electrocuted prior to the surveys.

Raptor Use of Power Poles

A total of 2,902 raptors were observed during the raptor perching surveys in the San Jacinto Valley and Owens Valley study areas. Red-tailed hawks were the most commonly observed species during both the surveys.

Raptor Electrocution Risk

The risk of death due to electrocution was very low in both of the study areas surveyed. Of the 12 fatalities found in the Owens Valley study area, four were excluded from analysis due to the age of the carcass when found. Therefore, for purposes of this analysis, it was assumed that as many as eight kills occurred during seven-month period of the surveys. Based on this assumption, the fatality rate was approximately 1.14 electrocution events per month during the course of the surveys.

In the San Jacinto Valley study area, it was assumed that three of the seven fatalities found occurred prior to the surveys. While it is possible that the remaining four fatalities were associated with electrocutions, evidence was not conclusive and these fatalities were not deemed to be electrocutions. Based on this assumption, the fatality rate was approximately 0.348 electrocution events per month during the 11.5-month course of the surveys.

To compare these two fatality rates, the fatality rate was indexed to the number of poles included in each survey route. This converts the fatality rate index for the San Jacinto Valley study area (n= 1,802 poles) to 0.00019 kills per month per pole surveyed. The comparable value for the Owens Valley study area is 0.00068. This would seem to indicate that the frequency of raptor electrocutions is 3.5 times greater in the Owens Valley study area than in the San Jacinto study area.

The risk of electrocution in the San Jacinto Valley region is extremely low when compared to that of the Owens Valley. For example, the fatality rate was lowest in the study area that supported the highest use by red-tailed hawks. The power pole use surveys indicate that red-tailed hawks perch approximately twice as frequently in the San Jacinto Valley as in the Owens Valley, yet their fatality rate is much higher in the latter study area. This is also true for golden eagles.

3.1.1.5 Conclusions

In general, there was a high degree of cooperation by SCE field personnel when it came to reporting raptor electrocutions. The procedures have been widely circulated throughout the company. Training and communications have been effective in getting the program implemented. The Raptor Protection Program has been in place for over a decade. It is standard operating procedure to report raptor electrocutions to SCE’s Office of Environmental Affairs.

It appears that primarily only those raptors that cause a circuit outage get reported. The field surveys confirmed that not all raptors that are electrocuted actually break the circuit and come to the attention of the maintenance personnel. This results in a general under reporting of the true extent of raptor electrocutions, both in the study areas surveyed and probably throughout the service area. There may be ways to set the sensitivity of the circuit breakers to be more responsive; however, there is a reluctance to do this because it may result in more frequent service interruptions.

3.1.1.6 Recommendations

During the course of the project, an electronic database was created of the historical records of raptor electrocutions on file with SCE’s Office of Environmental Affairs. This database should be kept current with new fatalities entered into the database as they occur. This will ensure thorough monitoring of the extent of electrocutions and the general distribution of the events. Using this database, priority areas needing modification to prevent perching or electrocution can be identified.

Raptor use of power poles cannot be predicted reliably by simply evaluating a pole's particular configuration, or its location on the landscape. Predicting electrocutions is even more difficult. Additional environmental factors unrelated to the physical characteristics of the poles almost certainly dictate whether or not a particular pole is used by raptors. These factors may include habitat conditions, topographic features, prey availability, and prey vulnerability specific to each raptor species and within the hunting radius of the pole. Also, remoteness from disturbance by people and vehicles may play an important role in raptor pole selection.

Future efforts to minimize raptor electrocutions should focus on the development of predictive models that: (1) identify regions, lines, or specific poles with a high probability of raptor use by vulnerable species, and (2) identify pole line configurations that have documented raptor electrocutions associated with them.

Once these models are developed and tested, utilities can inventory their distribution systems for the frequency of occurrence of individual poles assigned the highest ranking as potential problem poles. As resources permit, modifications and perch deterrents can be installed to further minimize the likelihood of future electrocutions. Using methods similar to those applied in this research will yield an index of raptor electrocutions that can be compared from region to region. Progress toward reducing electrocutions could be examined using pre-treatment versus post-treatment fatality survey data.

SCE's Raptor Protection Program is a useful tool for monitoring raptor electrocutions, identifying areas or individual poles needing modifications to reduce electrocutions, and educating SCE field personnel on the proper procedures to follow when a raptor electrocution occurs. It appears that the full extent of raptor electrocutions at SCE facilities may be under-reported. Steps to improve this situation need to be developed.

For more information on this Research Task Component see Appendix I.

3.2 Multiple Species Habitat Conservation Planning

3.2.1 MSHCP Workshop and Proceedings

3.2.1.1 Background

For years, the development of Multiple Species Habitat Conservation Plans (MSHCPs, or HCPs) has been identified as a preferred mechanism for dealing with the innumerable conflicts between endangered species and sustainable economic development. With over 500 state and federally-listed species within California, the potential for conflict between these species and proposed economic development, even ongoing activities for infrastructure maintenance, is very high. One of the ways that SCE believes that this conflict can be reduced is to have MSHCPs in place that provide a mechanism for protecting multiple species and their associated habitats, but also allow for development to proceed in a controlled and predictable pattern. This is a preferred approach over dealing with endangered species conflicts on a project-by-project or individual species basis.

3.2.1.2 Objectives

The goal of the MSHCP workshop was to facilitate the development of MSHCPs in California. SCE's goal in this workshop was to bring together some of the top experts involved in creating, planning, and managing MSHCPs, to allow for an exchange of ideas and thoughts. In this way, others involved in developing MSHCPs could benefit from the collective knowledge and experience of the participants.

3.2.1.3 Workshop Attendees

The multiple-species planning workshop was held from March 3 to 5, 1999 at the SCE offices in Rosemead. Attendees for all or part of the workshop included Dan Pearson, Jim Young, Bill Ostrander, Kim Gould, Kathleen West, Janet Baas, Cristi Tomlin, and Mike Hertel (SCE), Shawn Smallwood (UC Davis), Mike Morrison and Patrick Foley (California State University, Sacramento), Resit Akcakaya (Applied Mathematics), Steve Lacy (Ogden Environmental), John McCaull (National Audubon Society), John Bradley and Catherine McCalvin (USFWS), Tom Scott and Rick Redak (UC Riverside), Brian Loew (Riverside County Habitat Conseration Agency), Peter Bowler (UC Irvine), Robert Asher and Robert Copper (San Diego County), David Moser (McCutheon, Doyle, Brown and Enerson), Trish Smith (The Nature Conservancy) and Mark Sazaki (CEC).

3.2.1.4 Workshop Summary and Synthesis of Recommendations

Initial Expectations/Issues

Workshop participants began by listing key issues that were hindering successful completion and implementation of MSHCPs. Throughout the workshop, the group returned to this initial list to determine if these issues were being covered, and to supplement the list as new issues arose. The initial list was not meant to provide a group assessment, but rather to simply get issues on the table for discussion. The issues were:

- Avoidance of a "cookbook" approach to designing HCPs.
- The importance of developing standard applications of science to the HCP process.
- The relationship between the HCP enabling legislation (i.e., Section 10 of the Endangered Species Act) and the application of science to the HCP process.
- Incorporation of a rigorous Peer review process.
- Applications of ecological and population models to HCP development.
- The perspective of management and regulatory agencies into practical HCP development.
- In general, what steps can be taken to improve the HCP process?
- Methods to improve communication among all parties (stakeholders) involved in developing and approving a permit application, including pubic education and comment.
- The quality of the data that should go into developing an HCP, and how to deal with scientific uncertainty.
- What role do mitigation banks have in HCPs?

- Reserve design (including buffer areas), and the related issue of reserve management.
- The use of monetary incentives for improving HCP design and implementation, and in changing existing HCPs in light of new information.

Additional Issues

At the end of the first day of the workshop, participants reviewed the above initial issues list, and added the following items for further consideration:

- Should plans be written from the "bottom-up", whereby science drives the planning process; or from the "top-down", whereby major planning issues are first identified and then science is brought to bear on key issues In short, when should science enter the process?
- The role of HCPs as repositories for plants and animals that are being eliminated elsewhere through development.
- Public availability of data for use in development of HCPs.
- What is the likely direction for the use of HCPs into the future?
- How can an approved HCP be improved in light of new information? This topic relates to the issue of adaptive management.
- How can new research initiatives (to improve data quantity and quality) be incorporated into an HCP?
- How is "success" of an HCP measured?
- What is the proper role for HCPs to contribute to (Endangered Species) Recovery Plans?
- The problems associated with the lack of available expertise in developing and then reviewing a plan.

Conclusions/Guides for Improving HCPs

At the conclusion of the workshop, participants again reviewed their initial and modified lists of issues and expectations, and developed the following set of conclusions and recommendations for improving the HCP process.

- Revise the HCP handbook. There was general consensus that the current Handbook was too vague and did not provide adequate guidance on most aspects of HCP development. Sections that needed addition or strengthening included:
  - How to access and incorporate stakeholder input throughout the planning process.
  - Guidance on how U.S. Fish and Wildlife Service (FWS) personnel could be incorporated into all phases of a plan's development.
  - A clear discussion of adaptive management that cross-walked with current scientific literature on the topic.
  - Guidance on linking plan goals to measures of project success, and how success could be determined through post-implementation monitoring (e.g., study design, appropriate statistical analyses).
- A statement from FWS needs to be made regarding the use of population viability analyses (PVA) in plan development and evaluation; what are the data requirements

and allowable uses of a PVA? The goals for population modeling need to be clearly stated.

- The uncertainty associated with each major data set and decision in a plan needs to be clearly elucidated. This will allow plan proponents to have a better understanding of what they are proposing, and will allow all stakeholders to gain a better sense of the strengths and weaknesses of the data that went into a plan alternative.
- The standards for acceptable data (in plan development) need to be clarified. A general consensus emerged that "best available" data is too vague, because the "best" might not necessarily be reliable. Thus, the quality of each data set used in plan development must be clearly discussed.
- Standards should be established for how all material used to build an HCP are referenced. Although there was no consensus on how this should be reported to the public, it was agreed that a clear link between each decision within an HCP and the source of material used to arrive at that decision be established. For example, a decision could be based on anything from expert opinion to peer-reviewed literature. Identifying this link is essential for informed review of any plan.
- Independent peer review should be incorporated into each major stage of the planning process. This process would identify weaknesses in all data sets and preliminary decisions, and help reduce overall approval time of a plan.
- It was agreed that project management, including especially a detailed front-end scoping of a plan, be initiated by the FWS. This would help to more clearly identify major issues that need to be addressed early in the process.
- The issue of "species-based" vs. "ecosystem-based" plans needs clarification. Although there was consensus that plans should consider multiple species, it is important that all parties to a plan realize that "umbrella" or "indicator" species approaches seldom adequately protect all species covered under an HCP. This is because each species has unique habitat and niche requirements. Thus, an "ecosystem" approach is best understood as a "multiple-species" approach.
- Greater emphasis should be made on incorporating all stakeholders, including agencies, at all stages of the planning process. Greater attempts should be made to gather as much public input as possible throughout the process.
- It was agreed that the FWS has not been adequately funded by Congress to manage the HCP process. Thus, new funding mechanisms need to be developed to increase the number of personnel available. A recommended option was for permit applicants to financially support FWS and other agencies for personnel for the duration of a planning process. For example, there was agreement that an agency person should be assigned to assist with project management, and that the permit applicant should financially support an agreed-upon portion of the person's time. This would have the added benefit of increasing stakeholder involvement.
- People possessing a wider range of skills need to be incorporated into the planning process. Specific expertise areas needed include:
  - local land use planning issues and regulations
  - project management

- hydrology
- conservation biology, wildlife biology, and ecology
- knowledge of best land management practices (BMPs)
- engineering
- adaptive management
- study design (including impact assessment) and monitoring
- preserve management

- The specific goals of each plan over time must be stated, as well as specific criteria for measuring success of the plan.
- There appears to be general confusion on the role that an HCP can play in recovery of a species. The law specifically forbids an HCP to substitute for a Recovery Plan. However, HCPs are expected to contribute to species recovery. The FWS needs to better clarify the role of an HCP in recovering a species, especially given that HCPs usually permit take of covered species.
- All stakeholders need a basic understanding of project financing. This would help people understand what a permit applicant could and could not accomplish, with regard to mitigation and other plan requirements.
- There is often inadequate time available to fully design and implement an adaptive management approach into the HCP plan. As such, with the caveat that adaptive management should be incorporated early-on following plan approval, it was suggested that BMPs could be used to establish HCP preserves. Then, as data are gathered, a more formal adaptive management strategy could be implemented. Of course, the requirement for incorporation of such an adaptive management plan would need to be explicitly stated and designed into permit approval. However, BMPs allow evaluation of a proposed and developing preserve and the initial actions recommended for improvement of the habitat of specific covered species. There are many such models available (e.g., state forest practice rules), and efforts could be expended on synthesizing available data and expert opinion into developing BMPs for covered species. In addition, BMPs that address principles of reserve design and management can be gathered.
- The admittedly evolving nature of the HCP program administration by the FWS allows challenges of interpretation of the rules by permit applicants. The FWS needs to expend the resources necessary to establish firm guidance for its various offices and personnel throughout the United States.
- There needs to be clear guidance on what constitutes acceptable mitigation from the standpoint of endangered species policy. A helpful addition to HCP guidance by the FWS would be examples of recommended strategies for mitigating project impacts. Guidance involving major concepts of reserve design, the use of buffer areas and corridors, monitoring standards, etc. should be established. All guidance should be directly keyed to the relevant scientific literature.
- There was consensus that each HCP should contribute to the overall understanding of ecological processes driving the HCP concept. That is, projects should be planned so

that successes and failures in strategy and implementation can be documented and future projects can benefit from the knowledge. For example, if corridors are implemented as mitigation for fragmenting a preserve, then research should be incorporated into the monitoring phase of the project so the success of the corridor can be determined. This process should also instill confidence in all stakeholders regarding the seriousness of the FWS and permit applicant in devising a plan that promotes species survival. Such research-monitoring activities will be most successful if packaged with a workable adaptive management strategy that includes a funding vehicle for allowing future changes in the HCP.

- Each area and the species within it have their own unique distributions; HCPs should not become museum pieces of tiny fragments, rather they should cohesively act as protection measures throughout a species distribution, complementing but not replacing Recovery Plans.
- Lands to be developed ("taken") could be viewed as research tools, so that certain ecological experiments could be performed prior to habitat destruction. Additionally, consideration should be given to removing (transplanting) selected animals and plants if there is concern over loss of genetic diversity.

Workshop Presentations

Formal presentations were given during the workshop to provide background information, and serve as a catalyst for discussion. The workshop papers were divided into two major sections: Regulatory Issues and HCP Planning; and Conservation Biology and HCP Development. The first deals primarily with the legal foundation of the HCP process, perspectives from the standpoint of an environmental group and local and county governments, and weaknesses between the HCP Handbook and implementation of actual HCPs. The second section covers many of the scientific foundations of planning for multiple species preserves, including fundamental concepts of conservation biology, modeling the extinction process, landscape planning and wildlife habitat, and the lack of knowledge regarding the status of arthropods. Abstracts from the papers that were presented are located in Appendix III.

3.2.1.4 Deliverables

Dr. Michael Morrison and Dr. Shawn Smallwood, the workshop organizers, identified two sources of publication for the results of this workshop. A summary will be published in an upcoming book on Mediterranean ecosystems being edited and written by Dr. Peter Bowler. In addition, the papers presented at the workshop will be published in a special supplemental edition of Environmental Management.

For more information on this Research Task Component see Appendix III.

3.2.2 Population Dynamics, Dispersal and Demography of California Gnatcatchers in Orange Co., California (1998 Progress Report)

3.2.2.1 Background

The results presented here provide basic information about the biology of California gnatcatchers, a songbird species central to southern California's coastal sage scrub habitat conservation planning effort.

A critical aspect of the State of California’s Natural Community Conservation Planning (NCCP) program is the central role that science is intended to play in the formulation of land-use planning decisions and policies (California Department of Fish and Game and California Resources Agency 1993). By applying the principles of modern conservation biology to data on the distribution, ecology, and population dynamics of selected plant and animal species, an important objective of the NCCP is to design regional reserves that will ensure the long-term viability of rare and declining habitat types (O'Connell and Johnson 1997). Such a “proactive” conservation approach, if successful, may potentially halt the decline of sensitive species dependent on the habitats being considered, and thereby reduce the need to protect biodiversity through the cumbersome regulatory framework afforded by endangered species laws (Atwood and Noss 1994). Conversely, the NCCP may also identify areas that are scientifically determined to be less important from a biological standpoint, and where economic development may consequently proceed without fear of triggering further additions to federal or state endangered species lists.

The pilot project of the NCCP program has focused on a plant community known as coastal sage scrub (Reid and Murphy 1995), which is patchily distributed in southern California in the coastal lowlands west of the Transverse and Peninsular ranges. Historically, coastal sage scrub was a dominant feature of the southern California landscape, where it occurred widely in a natural matrix that also included grassland, chaparral, and oak woodland communities. Today, as a result of urban and agricultural impacts, 70-90% of the historic acreage of coastal sage scrub is estimated to have been lost (Westman 1981; O’Leary 1990), and those tracts of scrub that remain in the region generally occur as islands surrounded by ever-increasing urban development. Habitat loss and fragmentation have caused nearly 100 species and subspecies of plants and animals belonging to the coastal sage scrub community to decline to the point that federal and state wildlife agencies have formally designated them as endangered or threatened, or identified them as potential candidates for such listing (Atwood 1993).

The NCCP coastal sage scrub Scientific Review Panel selected three target species to use as the focus of conservation planning efforts for this habitat type: California gnatcatcher (Polioptila californica), cactus wren (Campylorhynchus brunneicapillus), and orange-throated whiptail (Cnemidophorus hyperythrus) (California Department of Fish and Game and California Resources Agency 1993).

Although different or additional species are, in practice, being used as surrogates for coastal sage scrub conservation planning in various areas of southern California, virtually all NCCP efforts that have been initiated to date have included maintenance of viable populations of California gnatcatchers as a principal objective. Sound ecological and behavioral information about this species will thus play a critical role in the preparation of NCCP plans and contribute to evaluation of the program's success.

3.2.2.2 Objectives

This study focuses on three objectives of direct importance to conservation and management efforts, and describes how long-term, detailed demographic studies can potentially clarify conservation issues affecting coastal sage scrub reserves. These objectives include:

- Collecting data on factors affecting patterns of dispersal by California gnatcatchers.
- Determining what factors influence annual variation in California gnatcatcher reproductive success, survivorship, and territory size, and what the implications are for research aimed at monitoring populations of these species.
- Developing GIS data layers delineating the extent of coastal sage scrub vegetation and the distribution of California gnatcatchers to examine factors affecting observed differences in California gnatcatcher densities, and attempt to identify those habitat characteristics that determine whether areas act as population sources vs. sinks.

3.2.2.2 Methods

Study Areas

This report includes information collected from six study sites in coastal Orange Co., California.

Population Survey

All major areas of natural habitat located in the six principal study sites were surveyed for breeding California gnatcatchers between February and June of each year of the study (1995 – 1998). Surveys were generally conducted before 11:00 a.m. and after 4:00 p.m., under weather conditions deemed acceptable in terms of wind and temperature. Tape recordings of gnatcatcher vocalizations were used to elicit responses. In areas where closely adjacent territories of unbanded birds posed potential confusion over the number of pairs actually present, teams of biologists would revisit the site in order to obtain simultaneous observations of all birds in question. Population estimates were based on observations of uniquely banded birds, the locations of simultaneously active nests, or simultaneous observations of unbanded birds. Survey intensity greatly exceeded the minimum effort required by U.S. Fish and Wildlife Service protocols (USFWS 1997).

Breeding Biology and Reproductive Success

Territories of focal pairs were visited between one and three days per week, beginning in early March and continuing into July or August. Nests were located through direct observation of nest building, nest exchanges, or feeding of nestlings. All successful nesting attempts of each of these focal pairs were detected. The number of juveniles fledged from each successful nest was based on counts, usually of banded birds, that were made one to five days after fledging.

To minimize potential impacts associated with monitoring activities, visits by biologists to gnatcatcher nests were generally limited to two to three occasions from the beginning of nest building to fledging. The initial visit was made when feeding of nestlings was first observed, in order to estimate the age of juveniles that were present and thereby schedule a follow-up banding visit. This second visit was then made when the gnatcatchers were approximately eight days of age; handling nestling gnatcatchers before this age was deemed impractical due to the birds' small size. We made no effort to expand the presently available data on clutch size, as our primary goal was to determine the total number of fledglings produced annually by each pair. Nests were not visited when western scrub-jays (Aphelocoma californica), loggerhead shrikes (Lanius ludovicianus), or brown-headed cowbirds (Molothrus ater) were seen nearby.

Japanese mist nets were used to capture adult and fledgling gnatcatchers for banding; birds were usually attracted to the vicinity of the nets by playback of recorded vocalizations. Two colored plastic leg bands were used in conjunction with the numbered USFWS.

Dispersal Behavior

Direct-line distances were used as the basis for evaluating the dispersal behavior of juvenile California gnatcatchers. Banding and resighting locations were described within a 1000-foot by 1000-foot grid pattern superimposed over each study area; distances were calculated between the centers of each of these grid cells using Arc/INFO's POINTDISTANCE function, and rounded to the nearest 0.1 km.

Survivorship

Survivorship estimates for adults and juveniles were calculated between the nesting seasons of

- 1993 – 1994
- 1994 – 1995
- 1995 – 1996
- 1996 – 1997
- 1997 - 1998.

Birds were included as being alive in a given year even if they were not actually recorded until following years.

3.2.2.3 Outcomes

Population Size and Distribution

Seventy-two to 96 breeding pairs of California gnatcatchers were found in the coastal Orange County study sites during surveys conducted from 1993 to 1998. Seventy-two pairs were located in 1998. Apart from a one-year increase that occurred during 1994, likely as a result of immigration of birds displaced by the Laguna fire of October 1993 (Atwood et al., 1999), populations in our study areas were essentially stable from 1993 – 1998.

Reproductive Success

Average gnatcatcher reproductive success in coastal Orange County from 1995 – 1998 was 2.64 fledglings produced per pair per year. There were no significant annual differences in gnatcatcher reproductive success among these years (Kruskal-Wallis test; H corrected for ties = 2.26, P = 0.52).

Reproductive success was compared between study sites dominated by Artemisia californica and sites where the coastal sage scrub community had a stronger chaparral component (including frequent dominance by Salvia mellifera). During each year of the study, there were no significant differences in the number of fledglings produced between these two categories of sites (Mann-Whitney U-test, $P > 0.05$). Other aspects of reproductive behavior have not yet been fully analyzed, but there was a significant difference in 1998 between Artemisia-dominated and Salvia-dominated sites in the frequency of occurrence of pairs with 0, 1, and 2 successful nesting attempts (Likelihood Ratio chi-square = 7.640, $P = 0.02$), with the relative rarity of 2 successful nesting attempts in Salvia-dominated sites especially deviating from expected.

Survivorship

California gnatcatcher survivorship data was summarized for adult and juvenile cohorts known to be alive in 1993, 1994, 1995, 1996, and 1997. Average survivorship was 0.197 for juveniles and 0.568 for adults (both male and female) based on combined data from both study areas. Because dispersing juveniles may easily move into areas where they are unlikely to be encountered as part of our research efforts, estimates of juvenile survivorship must be considered minimum values. In particular, because the Palos Verdes Peninsula functions as a closed system in comparison to Orange County study sites, estimates of juvenile survivorship to year one are probably more accurate from Palos Verdes than from Orange County.

Comparisons of survivorship estimates between Orange County and Palos Verdes failed to detect any significant difference between the two localities for adults of either sex (Mann-Whitney U-test, $P > 0.10$). Based on combined data from both study areas, there was no difference in mean survivorship estimates of males ($x = 0.52$, s.d. = 0.173, $n = 9$) vs. females ($x = 0.62$, s.d. = 0.159, $n = 9$).

Dispersal Behavior

No significant difference was found between Orange Co. and the Palos Verdes Peninsula in the dispersal distances of juvenile female gnatcatchers (Wilcoxon rank sum test, $Z = 1.48$, $P = 0.14$) or of juvenile male gnatcatchers (Wilcoxon rank sum test, $Z = -0.78$, $P = 0.43$). Consequently, data were combined from the two areas in order to increase sample sizes. No significant difference was found between the sexes in dispersal distance (males: mean = 2.95 km, s.d. = 2.68, range 0.0 - 10.2 km, $n = 92$; females: 2.48 m, s.d. = 2.14, range 0 - 10.1 km, $n = 104$) (Wilcoxon rank sum test, $Z = 0.99$, $P = 0.32$).

Annual differences in mean distances dispersed by juvenile gnatcatchers might conceivably reflect year-to-year differences in habitat saturation. For example, in years when regional population levels are high, relatively few areas of suitable and unoccupied habitat are presumably encountered by dispersing juveniles, thus requiring more extensive searches which result in longer average dispersal distances. In years when population levels are low, dispersing juveniles may succeed in discovering suitable, unoccupied habitat relatively near to their natal territories, resulting in lower average dispersal distances. Although there may be other factors involved which we have not yet addressed, this hypothesis appears to be supported by data collected in Orange County from 1994 to 1998. Juveniles fledged in Orange Co. in 1994, when gnatcatcher population levels were regionally elevated (Erickson and Miner 1998, Atwood et al. 1998a,b), had longer dispersal movements than cohorts fledged in 1995, 1996, and 1997 (Kruskal-Wallis Test, Chi-square = 10.1896, $P = 0.02$).

3.2.2.4 Conclusions

. These data are of major importance in evaluating existing conservation plans, guiding the preparation of new plans, and contribute to the ongoing refinement of habitat and species management objectives. These data go far beyond the typical "monitoring" activities that have too often characterized NCCP research efforts. While such monitoring projects are not without their value, mere counts of pair numbers will simply not provide planners, land managers, or regulatory authorities with the tools needed to understand and adaptively respond to specific conservation challenges (Science & Policy Associates 1997). This study (including now-terminated work on the Palos Verdes Peninsula) represents one of the only ongoing efforts aimed at collecting demographic and behavioral data for California gnatcatchers. Because of the major time investment involved in establishing uniquely-banded populations of known-age, known-natal area birds, and the value of such a study population in addressing regional conservation issues, the Palos Verdes / Orange County (coastal) project represents a critical research element contributing to the State of California's NCCP efforts.

For more information on this Research Task Component see Appendix IV.

3.2.3 Conservation and Management of Coastal Sage Scrub Habitat

3.2.3.1 Objectives

The aim of this task was to update the California Gnatcatcher model that was developed in a previous project, applying the gnatcatcher's interaction with its habitat to determine the best method to maintain management and conservation of coastal sage scrub habitats. The previous model was published in the journal *Conservation Biology* (Akçakaya and Atwood 1997). Changes were made to this previous model, using two years of new data that became available since the publication of the 1997 article.

3.2.3.2 Methods

The model is a spatially explicit, stage-structured, stochastic model of the California Gnatcatcher metapopulation in central and coastal Orange County. Model development started with a compilation of habitat data on vegetation and topography, and demographic data on survival, reproduction, and dispersal of the species.

The habitat data were used in a stepwise logistic regression, which estimated, for each cell, the probability of finding a gnatcatcher pair at that location, and thus reflected the suitability of the habitat. The resulting habitat suitability map was then validated by estimating the regression function from half the landscape, and using this function to predict the habitat suitability for known locations in the other half. The validated habitat suitability map was analyzed to calculate the spatial structure of the species' metapopulation (i.e., the number, size, carrying capacity, and location of its subpopulations), based on the distribution and quality of the habitat.

At the population level, the model for the California Gnatcatcher incorporated demographic data on survival, reproduction, and environmental variability for each population inhabiting a habitat patch. At the regional (metapopulation) level, it incorporated data on spatial factors that are important determinants of the risk of decline, including dispersal among patches, catastrophes, and spatial correlation of environmental fluctuations among the patches. The model was implemented in RAMAS® GIS 3.0, which is designed to link landscape data from a geographic information system (GIS) with a metapopulation model.

In the current update of the model, the only change in the patch structure was a “protected area mask” applied to the habitat suitability map, to mask non-reserve areas while allowing the proposed reserve areas to show through.

Estimates of demographic parameters were updated in several ways:

- New data from 1997 and 1998 were used, increasing the number of years of accumulated data from three to five.
- More of the parameters from Orange County rather than Palos Verdes were estimated.
- Parameter estimates for previous years were refined using data that were updated due to the continuing process of data entry and editing.

3.2.3.3 Outcomes

The new habitat suitability map included only the protected habitat, and assumed that the non-reserve areas will eventually become unsuitable for nesting, although they can be used for dispersal among reserve areas. Given this habitat map, the program found nine habitat patches (clusters of suitable cells within neighborhood distance of each other). The two largest patches made up about 86% of the total area of all patches. The total carrying capacity was 795 females, or (at stable distribution) 329 adult females. The total initial abundance was 636 females, or 263 adult females.

With the medium parameter estimates, the model predicted a substantial decline, but a low risk of extinction of the gnatcatcher populations. The risk of falling below the metapopulation threshold of 30 females within 50 years was about 10%. Although the extinction risk was low, the risk of a substantial decline was high.

3.2.3.4 Conclusions

Because of the uncertainty in most model parameters, and the sensitivity of results to these uncertainties, we suggest that the results should not be interpreted in absolute terms. Specifically, it would be inappropriate to use the results of this model to conclude that gnatcatcher populations in Central/Coastal Orange County are either threatened by extinction or secure from such a threat. There is too much uncertainty to predict with confidence what the population size will be in 50 years, or what the risk of extinction might be. Despite this uncertainty, the model can potentially have practical application in several areas. . These applications also indicate future research directions.

3.2.3.5 Recommendations

The research directions outlined below will lead to a set of practical tools for evaluating options for the management and conservation of the coastal sage scrub community.

Planning fieldwork and refining models with model-driven field research

Most parameters of a population viability analysis (PVA) model are known with a certain amount of uncertainty. Further fieldwork may yield data to narrow down these uncertainties and thus make model predictions more accurate and reliable. Analysis of the sensitivity of model results to various parameters provides guidance about what kind of data would be most efficient in terms of making the model predictions more reliable.

Expanding geographic coverage to southern California

An important limitation of the model is its geographic coverage. The coastal sage scrub in the study area may be connected to similar habitat in southern Orange County and elsewhere. Thus, the limits of the study area in central and coastal Orange County are somewhat arbitrary. One potential improvement to the model involves expanding it to include the populations of California Gnatcatcher in other areas.

Designing reserves

Reserve design, especially in a region as crowded as southern California, is determined by a large number of biological, economical, political, and social constraints. These constraints limit the number of feasible reserve configuration options. Metapopulation modeling can help provide scientific guidance to the process of reserve design by showing the environmental managers the ecological consequences of each option. This can be done by calculating the risk of decline for selected species under each reserve design option. Each reserve design option will then be associated with an economic (cost) and an ecological (risk of decline) consequence. This approach can also be used for other aspects of reserve design, such as designing habitat corridors and other connecting habitats, or adding small, “stepping-stone” habitat patches to existing reserves.

Testing management options

In principle, all possible management actions can be represented as changes in habitat suitability or demographic parameters, once the effect of these management actions is described in terms of model parameters. The consequences of these changes are estimated by the model in terms of the viability of the species, and then used to rank alternative management actions, to prioritize conservation measures, and to evaluate the relative importance of different parameters.

Assessing human impact

Assessment of human impact can be done in a way similar to the evaluation of management options. Each impact affects the population in a specific way. These effects can be quantified as changes in model parameters or structure. For example, habitat loss may decrease the carrying capacities of affected habitat patches; fragmentation can change the spatial structure of the metapopulation; pollution and widespread degradation of habitat quality may affect vital rates such as survival and fecundity; and geographic barriers may lead to both fragmentation and a decrease in connectivity (dispersal rates among patches).

Reserve design and management from a multi-species perspective

The habitat-based metapopulation modeling approach described above can be applied to a list of selected (e.g., “indicator,” threatened, or sensitive) species. This results in habitat suitability maps and metapopulation models for all species in the list. The outcomes of the model simulations are used to estimate the risk of extinction or decline of the species in the whole region, as well as the importance of each location for the viability (persistence) of the species. Each of the individual habitat suitability maps can then be combined into a single aggregate map (a "multi-species conservation value" map) that expresses the worth, in conservation terms, of the locations. The habitat suitability maps can be combined mathematically by using a weighted average of all of the maps (Akçakaya 1999).

It is important to note that Habitat Conservation Plans, as well as plans for the management and design of multiple species reserves, will work only if they are based on sound science. One of the most powerful scientific tools that land managers and decision-makers can use is PVA of selected species. These methods can be used to:

- Aid various types of decisions in the design and management of multi-species reserves.
- Guide fieldwork in order to use resources in the most efficient way.
- Support reserve design decisions with a science-based comparison of the design options with respect to their ecological and economic consequences.
- Evaluate management options and impacts in terms of their effect on the viability of selected native species.
- Identify ecological "hot-spots," i.e., areas of high conservation value from a multiple species perspective.

For more information on this Research Task Component, see Appendix V.

3.2.4 RAMAS® Ecological Risk Model for Desert Tortoise

3.2.4.1 Background

The desert tortoise, federally listed as threatened, is by both extrinsic (e.g. habitat destruction / degradation, drought) and intrinsic (e.g. low juvenile survival, delayed maturity) factors. The greatest threats to the tortoise and its long-term survival appear to be human intrusion in the desert tortoise habitat. Long-term data indicates that the populations of this species are declining, although some regions appear more vulnerable than others.

The desert tortoise is a long-lived herbivore restricted to arid habitats in California, Nevada, Arizona, Utah, and northwestern Mexico. Desert tortoises spend 98% of their time in burrows, which they excavate and defend, emerging in the spring to feed, mate, and lay eggs. Most desert tortoises reach sexual maturity at approximately 180mm in carapace length (i.e., 8-20 years of age). Reproductive output of females varies from 0-3 clutches per season with 1-14 eggs per clutch, depending on winter rainfall and forage availability. Regional abundance estimates vary. In the western Mojave, some declines in desert tortoise numbers have been documented. In other regions, such as the eastern Mojave, populations appear to be stable. Tortoises move extensive distances for foraging and finding mates, but freeways are deadly for the tortoise and restrict these movements. The fundamental problem is that the desert tortoise is widely distributed, long-lived, and has delayed sexual maturity, making this species vulnerable to human impact and habitat destruction and loss.

3.2.4.2 Objectives

This project focused on the potential effects on the desert tortoise metapopulation resulting from construction of transmission lines in tortoise habitat. Construction of transmission lines is likely to reduce the amount of available suitable habitat for the tortoise and were simulated in the model as a reduction in the carrying capacity. Another potential effect of transmission lines is the increase in the number of raven predators. Recent studies have suggested that raven density increases along utility corridors and that ravens are a major predator of juvenile desert tortoises. As such, ravens pose a threat to the long-term viability of local populations. In the model, we simulated the impact of raven predation using a reduction in the survival of tortoises that were <100mm in carapace length.

The goal was to build an assessment tool for the evaluation of the population-level risks to the desert tortoise from utility transmission line siting or modification, or from maintenance operations associated with transmission lines in the Mojave Desert of California. Specifically we examined factors affecting the long-term viability of the desert tortoise in California, Utah, Nevada, and Arizona using a stochastic metapopulation model.

3.2.4.3 Methods

A regional-scale metapopulation model for the desert tortoise is an excellent tool to address long-term management and conservation issues. Such a model includes:

- Length / age-specific demographic parameters
- Abundance estimates for Mojave Desert tortoise populations
- Estimates of annual variability in demographic parameters
- Environmental stochasticity
- Density dependence
- Effects of impact factors such as predation or habitat destruction / loss.

Data on annual rates of survival and reproduction, population abundance, dispersal probability, and density dependence were required for this model.

Extensive mark-recapture studies have been conducted at the Goffs study site in California in the Eastern Mojave Desert. Much of the demographic information available on desert tortoise comes from these studies. Additional studies have been conducted on land owned by the Bureau of Land Management (BLM) scattered throughout the range of the desert tortoise. Tortoises west of the Colorado River differ ecologically and genetically from populations east of the river, and are currently listed as threatened by the USFWS. So, for this study we included only those populations that were west of the Colorado River, in California, Nevada, Utah, and Arizona.

Using RAMAS® GIS (v.3.0) for Windows 95, we incorporated the available data on survival, growth, fecundity, and the year-to-year variability of the demographic rates from empirical studies at Goffs, California on BLM lands, and from published literature. We constructed a female-only, carapace-length-based, eight-stage population model. In the model, only female tortoises larger than 180mm in carapace length reproduced, based on clutch data from Goffs. In the Desert Tortoise Recovery Plan (1994), 12 Desert Wildlife Management Areas (DWMAs) were designated in six Recovery Units. We used these DWMAs as the basis for the location of the desert tortoise populations west of the Colorado River.

These DWMA-based populations were large and comprised of both suitable and unsuitable habitats for the desert tortoise. Using a GIS habitat suitability analysis based on the vegetation coverage (GIS data obtained from University of California Santa Barbara (UCSB) Gap database, which was partially funded by SCE, the USGS National Gap database, and the Mojave Desert Ecosystem Database Project), the area that was suitable for tortoises was estimated in square kilometers. These were digitized in ArcView in two different ways. In the unfragmented scenario, it was assumed that any populations that were contiguous represented a single population. With this assumption, the 12 DWMA's become eight desert tortoise populations. Alternatively, in the fragmented scenario, we assumed that roads and rivers represented an insurmountable barrier to tortoise dispersal. The map, therefore, includes 26 distinct polygons or populations for desert tortoises in California, Utah, Nevada, and Arizona.

There were two sources of density estimates for these populations. Between 1977 and 1989, tortoises were captured and measured at 20 BLM plots scattered throughout the region. These captures were used to estimate densities. In the Desert Tortoise Recovery Plan (1994), a range of densities was given for each the 12 regions. For populations that included parts of more than one DWMA, the average density of the individual DWMAs was chosen for the population. The maximum DWMA density estimate, or the BLM maximum density estimate, if available, was used to calculate the carrying capacity for each population.

In the model, some assumptions were made about dispersal among populations. In the fragmented metapopulation, tortoises did not cross the roads, i.e., no dispersal was allowed across the highways. Within a year, a maximum of 5% of a population could migrate equally into the neighboring populations. In the fragmented metapopulation, tortoises in populations seven and eight were completely isolated from all other populations by roads, but tortoises could travel from population six to population ten and vice versa.

Little is known about density dependence in desert tortoise populations. Tortoises use burrows and do defend them, which indicates a degree of territoriality. As a cautious approach to density dependence in the absence of data, the model includes a density ceiling or carrying capacity (K), which was assumed to be the maximum observed density in field studies. As a less pessimistic alternative, simulations were run with scramble competition for populations with fecundities greater than zero, and with the ceiling described above for the remaining (severely declining) populations. The carrying capacity (K) was specified for all populations as described above and the maximum population growth rate (R_{max}) was either 1.025 or 1.05 (i.e., an average annual increase of 2.5 or 5%).

In addition, we customized the RAMAS® GIS model to address specific ecological issues, e.g., raven predation, and utility activities such as maintenance, construction, and siting. Assuming that a single line running through a population eliminated 116.5km^2 of suitable habitat (based on literature estimates), the potential effects of the new transmission lines can be modeled as a reduction in the carrying capacity of the affected population. We examined four possible siting scenarios: one line passing through each of the five largest populations, one line passing through each of the five smallest populations, one line passing through each of the fifteen smallest populations, and one line passing through each of the twenty six populations. In each affected population, we reduced the carrying capacity by 116.5km^2 while keeping all other parameters the same as in the previous models. In the metapopulation model, the impact of additional mortality on juveniles was incorporated to assess the impact an increasing number of ravens might have on specific tortoise populations. Since there are no direct data that indicate the actual rate of predation, we assumed that ravens would increase the mortality of the classes 0-2 (less than 100mm in carapace length) either 10% or 20% annually in an affected population. For these predation scenarios, we assumed that only the youngest three classes were affected and that no habitat was lost.

The analysis of the metapopulation dynamics with the model described above consisted of a series of simulations. Each simulation had 10,000 replications, and each replication projected the abundance of each population for 100 time steps (years). The resulting graphs, available in Appendix VI, show risk of decline (within the simulated time horizon) as a function of amount of decline. Statistical significance was estimated using the Komogorov-Smirnov test for the maximum vertical distance between two terminal percent decline curves.

3.2.4.3 Outcomes

The model makes a number of predictions. Fragmentation, habitat loss (reduction in carrying capacity) and raven predation increase the risk of a decline in abundance for the tortoise metapopulation. The magnitude of the increase in risk from these factors is dependent on (1) the magnitude of the impact (e.g., 10% vs. 20% predation), (2) which populations are affected by the impact (e.g., large versus small populations), and (3) the assumptions about density dependence. The largest increase in risk due to habitat loss occurred when applied to only the smaller populations, i.e., an 18% increase compared to comparable scenarios with no habitat loss. For raven predation, the largest increase (10-54%) occurred when applied to only the larger populations, depending on the level of predation, and the risk of a decline compared to comparable scenarios with no additional predation.

The results of this model suggest that the potential impacts of transmission line siting and maintenance were dependent on which populations were affected, but the effects were usually moderate. The baseline risk of a 50% decline in the metapopulation abundance, though, was quite high with no additional impacts except under the most optimistic density dependence assumptions. This finding supports empirical studies indicating that these populations are experiencing a large decline in abundance. The model and the results would be strengthened by additional data on density dependence in natural populations, such as carrying capacity and maximum growth rate, and on the effects of raven predation.

3.2.4.4 Recommendations

As this analysis has shown, ecological risk assessment is a valuable management tool that allows comparison of alternatives even with limited data, and highlights future research needs. Additional empirical studies of the tortoise are warranted, especially in the area of density dependence and predation. Given the assumptions in the model, though, the potential impact of a new transmission line may be estimated with this technique given the specific location and extent of the line, and compared with alternative plans. Also, as additional data are accumulated, the metapopulation model can be easily modified to incorporate the new information and assess the effects.

For more information on this Research Task Component, see Appendix VI.

3.2.5 The Metapopulation Model as an Educational Tool: Providing Internet Access to RAMAS® GIS Software

3.2.5.1 Background

In this project, we developed a version of RAMAS®, downloadable from the World Wide Web (WWW), which allows users to run metapopulation models based on the real-world examples of the desert tortoise and the California gnatcatcher. These models serve as an excellent educational tool. By placing a version of the metapopulation model on the WWW, members of the public may test the alternatives for themselves. In addition, the models serve as a vehicle to SCE's and the Electric Power Research Institute's commitment to environmental issues and their research efforts. Users can pose a question, examine the modeling predictions, and draw their own conclusions. Students will have the opportunity to learn about the methods and tools used for PVA and risk assessment. Not only does this demonstrate the efficacy of the technique used, but it allows a broader public participation in important regional issues.

3.2.5.2 Objectives

The goal of this project was to develop an interactive web site that allows users to accomplish three things:

- Learn about the research that SCE has funded on conservation of the California gnatcatcher and the desert tortoise.
- Explore the methods and results themselves by downloading the software, using the input provided, and running the models themselves.
- Learn about current methods in conservation, including PVA, and their applications to real-world issues.

3.2.5.3 Methods

The program RAMAS® GIS was modified and compressed to be readily downloadable off of the Internet. Sample data files that included the necessary demographic and spatial elements for use in RAMAS® GIS were created for the desert tortoise and the California gnatcatcher metapopulation models. Help instructions for the program and a tutorial that guides users through the provided example files were developed.

A web site was created on the WWW to host the demo version of RAMAS® GIS (*http://www.ramas.com/demo/tortoise/index.htm*) and the additional sample files, data, support documents, and general guidance on the use of the program and how to interpret the results. Included on the site are the background materials, description of data utilized, and an interactive version of the metapopulation model. The web site provides important information for potential users of RAMAS® GIS, such as guidance on the use of the program and on the interpretation of the risk results of the program. The documents are in a format that is suitable for the web and can be downloaded for the user's convenience. Additional information is provided on the specific examples that are available for use in the program.

For the desert tortoise project, a slide show was created. In the slide show, basic tortoise biology is explained, as is why it is vulnerable to human intrusion into its habitat. Some of the issues that face desert tortoise populations in their habitat are outlined, and one approach to addressing these issues is described. The slide show then demonstrates step-by-step how the metapopulation model was constructed, parameterized, and run in RAMAS® GIS. Some example results are shown and discussed, and the slide show finishes with some conclusions and recommendations.

For the California gnatcatcher portion of the web site, some of the relevant issues for the species are presented. The basic approach to these issues is described and the results are displayed. Details of the model, its parameters, and its construction are provided in a tutorial where users examine the model in RAMAS® GIS, which they have downloaded.

3.2.5.4 Outcomes

There are three sections to the web site that are launched from the main page (*index.htm*). A schematic diagram of the web site is shown in Figure 1.

- Part 1: Conservation and Management of Coastal Sage Scrub
  - Project description and sample file tutorial (accessed via files: *gnat.htm* and *gnattutr.htm*, respectively)
  - Sample model files (*gnatmdls.zip*) that compare three hypothetical management strategies
- Part 2: Desert Tortoise Metapopulation Dynamics (Phase II)
  - Project description in the form of a slide show (accessed via file: *title.htm*)
  - Sample model files (*tortmdls.zip*) that examine seven different parameter sets
- Part 3: The metapopulation model as an educational tool
  - RAMAS® demo program available (*rgdemo.exe*)
  - Help files in Acrobat form (*readme.pdf*) or as a text file (*readme.txt*)
  - Two additional sets of models (*gnatmdls.zip* and *tortmdls.zip*)

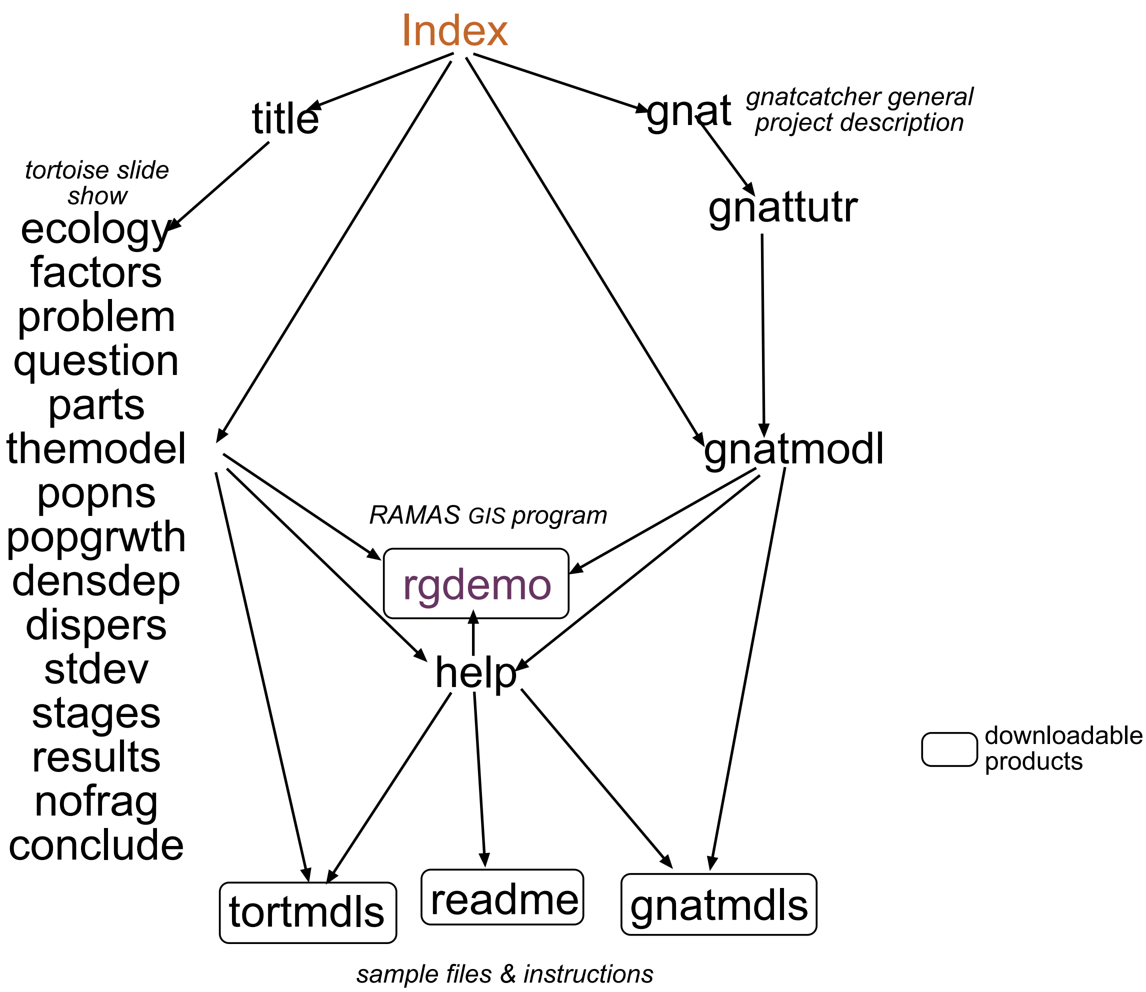

Figure 1. Schematic diagram of the RAMAS® web site

3.2.5.5 Conclusions

We believe this web site will serve as an excellent educational tool. It also highlights SCE's commitment to environmental research and conservation of native species. This research utilizes state-of-the-art communication media (the internet) to deliver the state-of-the-art conservation technology (RAMAS® software) and emphasizes the application of technology to solving real-world problems.

For more information on this Research Task Component, see Appendix VII.

3.2.6 Comparison of IUCN and USFWS classifications of threatened species

3.2.6.1 Background

The Endangered Species Act (ESA) was implemented in 1973 to prevent extinction of animals and plants through the protection of their ecosystems and the development of specific conservation programs (USFWS 1998). The ESA authorizes officials to categorize species facing risk of extinction as either endangered or threatened, based on the magnitude of extinction risk.

Federal agencies are then obligated to carry out conservation measures to protect these species by imposing regulations to preserve critical habitat or to restrict harvesting levels as deemed essential for their conservation.

Assessing the extinction risk of species is imperative for implementing effective conservation strategies and for apportioning limited financial and human resources for species conservation. The determination to list a species as endangered or threatened is, therefore, one of the most critical steps for reaching the objectives of the ESA. Yet, the protocol for prioritizing taxa for protection has been criticized by some in the scientific community as being arbitrary because there are no explicit guidelines by which these decisions are made. The use of biological criteria in the decision-making process is inconsistent, and descriptive variables often receive more consideration than quantitative variables.

2.3.6.2 Objectives

Despite criticisms of the USFWS listing protocol, few quantitative or systematic analyses of the system have been conducted. In this study, the USFWS listing protocol is evaluated by comparison with another system used by the international conservation organization known as the World Conservation Union (IUCN). Risk classifications of 60 species were examined under both the USFWS and the IUCN systems and compared.

3.2.6.2 Methods

Sixty animal species native to California were classified according to criteria from the IUCN and the USFWS. The degree of correspondence between the classification systems was then examined. IUCN classifies each species into one of four categories (Critically endangered, Endangered, Vulnerable, and Lower risk) based on ecological variables such as number of mature individuals, recent declines, geographic distribution, and extinction risk. USFWS classifies species at risk into one of two categories (endangered and threatened) based on magnitude and immediacy of threat and taxonomic uniqueness.

If a species was previously evaluated by IUCN, its status was taken from IUCN. Species chosen that were not already listed by the IUCN were classified according to the IUCN criteria. Information concerning the populations of each species and their habitat was collated from the scientific literature and from USFWS status reports. This information was then incorporated into RAMAS® RedList (Applied Biomathematics, Setauket, NY), a program that uses numerical thresholds of ecological variables to classify species according to IUCN criteria. Twenty-four of these species were not listed by the USFWS (USFWS 1999) and could not be evaluated confidently because the USFWS criteria for listing species are not explicit.

A comparison was made between the IUCN and the USFWS classifications. It was assumed that IUCN’s lower-risk category corresponds to the species not listed by the USFWS. The highest-ranked categories of IUCN, (critically endangered and endangered) were assumed to correspond to the USFWS category endangered. Because there are fewer categories under the USFWS system, it was also assumed that threatened corresponds to both endangered and vulnerable categories of the IUCN. The degree of disagreement between classification systems was determined from the proportion of species that did not fall within the corresponding categories.

3.2.6.3 Outcomes

A comparison of the two systems revealed a large degree of correspondence between the criteria used by USFWS and by the IUCN. The only USFWS criterion that does not have an explicit counterpart in the IUCN criteria is “Not adequately protected by present laws and regulations” (FWS criterion 4). However, those species that are not adequately protected will have:

- Declining area of occupancy, area, extent and / or quality of habitat, number of locations or subpopulations or mature individuals (IUCN criterion B2), or
- Continuing decline in numbers of mature individuals, combined with fragmentation (IUCN criterion C2), or
- A high risk of extinction (IUCN criterion E).

Thus, although protection by existing laws and regulations is not an explicit part of the IUCN criteria, the effects of the lack of such protection are reflected in at least three of the criteria.

The correspondence between the USFWS and the IUCN listing categories were compared for 60 native California species. The listing status of 19 of them (31.7%) did not fit into corresponding categories of the IUCN and the USFWS. Eight species were listed in a higher endangerment category by the USFWS, while 11 were either not listed (9) or listed in a lower threat category (2) by USFWS. Of the nine species that were not listed by the USFWS, it is unclear how many have not been evaluated and how many were evaluated but considered to have a low extinction risk. When these species were not considered in the comparison, ten of the remaining 51 species (15.7%) were listed in USFWS and IUCN categories that did not correspond to one another.

3.2.6.4 Conclusions

The inconsistent use of biological criteria and heavy reliance on qualitative variables by the USFWS result in a low correspondence with the IUCN system and with its own “degree of threat” ranking under the recovery priority listing system. The low correspondence with the IUCN categories was found in spite of the assumption that each USFWS category corresponds to two IUCN categories.

The IUCN listing system has several advantages over the USFWS protocol. The IUCN listing process was developed under wide consultation and is recognized internationally by the public and scientific community. The lists of threatened species developed by IUCN are among the most widely used by conservationists around the world. The IUCN criteria were designed to detect risk factors for organisms of widely different taxonomic groups. While all criteria might not be relevant for a particular taxon, there are criteria relevant for assessing extinction threat of all groups (except microorganisms).

3.2.6.5 Recommendations

Resources for conservation of species are limited. It is, therefore, imperative that decisions are made carefully to focus on species that will receive the most benefit from conservation agents. Also, many species at risk of extinction cannot afford an inefficient listing protocol. These considerations are mentioned in the Endangered Species Act of 1973, yet the present process is both slow and subjective. To revise the federal system, we suggest a new decision making process be developed that is similar in structure to the IUCN system that could easily be modified to satisfy the specifications of the ESA.

For more information on this Research Task Component, see Appendix VIII.

3.3 California Habitat Evaluation

3.3.1 Procedures for Creation and Use of ADAR-Based Vegetation Maps to Support Habitat Management

3.3.1.1 Background

This report presents results of research to develop methodologies for mapping and monitoring critical California habitats using Airborne Data Acquisition and Registration (ADAR), a high-resolution airborne multi-spectral imaging system. The study is part of a long-term research program initiated by SCE as early as 1995. SCE's California Habitat Evaluation Research Program began with research to apply ADAR technology to monitoring coastal wetland habitats (Phinn et al, 1996). In its second stage, the program extended the use of ADAR’s imaging capabilities to the mapping of coastal sage scrub, a habitat of special interest in Southern California and the subject of the State of California’s ambitious Natural Communities Conservation Program (NCCP). Research in this second stage demonstrated that ADAR can be used to identify and map components of the coastal sage scrub community, as well as related communities such as chaparral, grassland, sycamore woodland, etc. (Brewster et al., 1998). The research described in the present report, conducted during the period from June 1998 to June 1999, represents the third stage of the program, with the goals of further enlarging the mapping and monitoring capabilities of applied ADAR technology and of bringing the technology closer to operational (rather than experimental) use. The specific objectives of stage-three research are described in detail in the section that follows.

The fourth stage of the California Habitat Evaluation Research Program, designed to follow upon the now complete third stage, includes goals of adding conifer forest and related woodland communities to the repertoire of habitats that can be mapped effectively using ADAR, and making time-sequence (multi-year) monitoring fully operational.

The overall goals of the research program, and of the present study in particular, serve several needs. Mapping and monitoring of critical habitats is a vitally important function to managers of habitat preserves. Development of ADAR technology as a mapping and monitoring tool therefore supports the conservation goals of the State’s NCCP. As a pioneering “habitat-based” conservation program, the NCCP is just now entering its implementation phase, and the newly entrusted managers of participating preserves recognize a need for new, cost-effective technologies to assist their efforts (Almanza, 1998). The availability of ADAR technology to support management of preserves will not only assist SCE, as a permittee with coastal sage scrub habitat in NCCP preserves, but can also assist other NCCP participants (such as San Diego Gas & Electric) as well as the regulatory public agencies (California Department of Fish & Game and USFWS). Mapping and monitoring tools also have the potential to serve conservation needs within California. As multi-species and habitat-based conservation programs proliferate in California, the demand for cost-effective habitat management tools will increase. As a rapid, efficient method for collection of digital, landscape-level data, ADAR has the potential to provide the real-time data necessary to drive monitoring and management tools such as RAMAS® and other meta-population models. Development of mapping and monitoring tools through this research lays the groundwork for a wide range of capabilities that comprise the toolbox for managing California's legacy of habitat preserves.

3.1.1.2 Objectives

The objectives of research conducted in 1998-99 are:

- To enlarge the mapping capabilities of ADAR methodologies to include numerous habitat types not previously established within the technology's repertoire. The additional habitats (several dozen) were studied through two new study sites, each offering a range of plant communities not found within previously studied sites. These two sites, Hidden Ranch (or Black Star Canyon) and the Etiwanda Alluvial Fan (located in Rancho Cucamonga), were each selected for the diversity and the critical character of their habitats. Among the new plant communities studied at the Hidden Ranch site are:
  - Chamise Chaparral
  - Maritime Chaparral-Sagebrush Scrub
  - Purple Sage Scrub
  - Southern Willow Scrub
  - Needlegrass Grassland
  - Coast Live Oak Riparian Woodland
  - Coast Live Oak / Chamise Chaparral Woodland

  Newly studied communities provided by the Etiwanda site include:
  - Alluvial Fan Sage Scrub (Pioneer, Intermediate, and Mature phases)
  - Alluvial Fan Chaparral
  - White Sage Scrub
  - Ceonothus Chaparral
  - Walnut Woodland

  The application of ADAR methodologies to such a diverse range of plant communities allowed the research team to better ascertain the limits and capabilities of ADAR as a mapping tool and some of the conditions that influence ADAR's efficiency.

- To examine the feasibility of detecting changes in habitats over time, based on multi-date ADAR imagery. Research of ADAR's change detection capabilities included developing procedures for locating differences in images from one year to the next, and identifying the relationship of image differences to actual changes on the ground. Image differencing requires co-registration of year-to-year imagery and employs "differencing" procedures. This study examined the relative success of several differencing procedures. The Sycamore Hills site in coastal Orange County, which had been mapped using ADAR in previous years, was the study site for these procedures.

- To describe the relative costs and benefits of using ADAR for mapping and monitoring compared to using conventional mapping methods. Habitat mapping by conventional methods usually involves field surveys conducted by one or more biologists, typically labeling polygons corresponding to plant communities hand drawn over black and white or color aerial photographs. This study identifies conditions when it would be more cost-effective to employ ADAR to map vegetation, the special capabilities of ADAR not available through conventional methods, and the factors that influence the relative costs and benefits of both methods.
- To synthesize the procedures employed in the various tasks and case studies of this research, and to present them in a well-documented format to be used as a Procedures Handbook by SCE's GIAS Laboratory staff. The purpose of the Procedures Handbook is to enable staff to learn and execute the procedures developed through this research for the acquisition, post-processing, and classification of ADAR data in order to produce habitat maps.

The multiple objectives of this research lend a complexity to the project. It is a research project, because of the research required to develop and test refined procedures. It is a demonstrations project in its application of procedures to multiple study sites. It is a comparative analysis that addresses relative benefits of different methodologies. And it is a documentation process designed to transition newly developed procedures into an operational phase.

3.3.3.2 Methods

Habitat Mapping

Three different methods of converting ADAR image frames to image maps were examined to compare their relative cost-effectiveness:

- In-house image processing
- Processing by the vendor
- Processing by third parties

The products of each of these procedures were evaluated for precision (root mean square error) as well as cost and turn-around time in obtaining the product. The use of three different study sites provided the opportunity for case studies to test and evaluate five different in-house methods of in-house image registration and mosaicking. These included:

- Registration and mosaicking to a GIS database
- Registration and mosaicking with GPS coordinates
- Registration and mosaicking with a digital orthophoto quarter quadrangle (DOQQ)
- Registering to existing ADAR image and mosaicking
- Registering and mosaicking using Orthomax software

Habitat mapping at the two new study sites (Hidden Ranch and Etiwanda Alluvial Fan) was performed using the same general methodology previously used for the Sycamore Hills site (Brewster et al., 1998). In the case of Hidden Ranch, ground reference vegetation data was provided in GIS form, prepared under separate contract for SCE by a biological consultant (PCR, 1998). Data for the Etiwanda site was developed for this study by consulting biologist

David Bramlet, based on site visits and both black and white and color aerial photographs converted by researchers into GIS (ArcInfo) format.

Change Detection

Five alternative methods for change detection were tested and evaluated. Change detection procedures were applied to Sycamore Hills image data from 1996 and 1998. The methods examined included:

- Spectral image differencing
- Change vector classification
- NDVI differencing
- Texture differencing
- Post-classification comparison

Comparative Methodologies

Relative costs and benefits of mapping and monitoring using ADAR-based methods compared to conventional methods were ascertained using actual costs derived from our case studies and from the researchers' familiarity with current costs for generic tasks associated with both methods. The important factors that influence relative benefits and costs were described, based on researchers' experience with both conventional and ADAR-based procedures and the quantities of labor, software, hardware, and expertise required to perform specific tasks.

Preparation of Procedures Handbook

Procedures used by researchers to develop image maps from raw ADAR data were carefully documented and described step-by-step so they can be easily followed by SCE GIAS Lab technicians. The Lab staff was provided with the unprocessed ADAR data used in the study, allowing them to apply the procedures themselves and test the Handbook's utility. Their comments and suggestions were based on their interactive, hands-on review, and are incorporated into the Handbook's final version.

3.3.1.3 Outcomes

Habitat Mapping

Results of our comparison of methods indicate that third-party geometric processing of ADAR image data is not currently cost-effective. This is due in part to the rapidly evolving and unperfected state of commercially available image processing technologies. Two different third-party providers were asked to provide processing services. The Hidden Ranch data were provided to ID Vision, Inc., which resulted in a product with low positional accuracy, poor documentation, no header or metadata, and slow turn-around. The cost for this low-quality product was also relatively low. The Sycamore Hills image data were provided to Vexcel Corporation, which also returned a product with slow turn-around and unacceptably low root mean square error.

The five alternative in-house geometric processing procedures were each performed with relative success. The resulting precision varied according to the degree of topographic relief at each of the study sites and according to the quality of available reference data (i.e., GIS database, DOQQ, existing ADAR image). The preferred method depends on three main variables: site characteristics, available georeference data, and mapping objectives. For multi-date monitoring applications, registration to an existing ADAR image map is usually preferable (depending on the quality of the existing image). For other applications, the preferred procedure is to use a high-quality georeference data source such as a DOQQ or Digital Elevation Model (DEM), the latter preferably created from aerial photographic stereo pairs. Orthorectification using GPS points can also achieve a high degree of positional accuracy, although collection of GPS points in the field can be time consuming.

Vegetation Mapping

Classification of habitat types based on ADAR image data was achieved with a satisfactory degree of accuracy for both the Hidden Ranch and Etiwanda sites. At the Hidden Ranch site, differences between the map produced by field biologists (conventional methods) and ADAR classification are mostly attributable to standard sources of error: mapper subjectivity, image displacement, and limited field verification. These errors were committed to some degree by both methods, the magnitude of error and the differences between them accounting for most of the discrepancies.

Because ADAR-based classification is computer-assisted, classification criteria can be codified to allow for more consistent application, potentially reducing subjectivity error. Image displacement error can be more readily corrected using ADAR-based data through application of softcopy photogrammetry and auto-registration. The need for field verification is common to both methods, although ADAR's ability to image inaccessible areas can reduce the need to visually inspect all areas of a study site.

Change Detection

Land cover changes and/or changes in habitat quality were detected by several of the change detection techniques employed. Results of the study demonstrate that important information about habitat condition and change in condition can be derived from ADAR imagery. Changes at the Sycamore Hills site during the two-year period from 1996 to 1998 that were detected from ADAR imagery include:

- Trail widening
- Invasion of poison oak into coastal sage scrub
- Sedimentation in a grassland environment
- Regrowth of vegetation in a previously unvegetated area

These results are significant in establishing the potential value of ADAR imagery as a monitoring tool (as distinct from mapping) for habitat management purposes.

Comparative Costs/Benefits

Comparison of relative benefits of using ADAR technology rather than conventional mapping methods indicated that ADAR has distinct advantages over conventional techniques, which inevitably translates to greater cost-effectiveness. This is especially the case when:

- The need for mapping is repetitive, i.e., a need for frequently refreshed data (three to five years or more)

- The application calls for landscape-level monitoring, particularly monitoring that is specific, purposeful, and related to one or more hypotheses concerning changes in the environment
- The data collection will meet the needs of multiple applications and / or parties
- The resources to be mapped cover an area of medium to large size (at least a few hundred acres)
- The appropriate facilities and personnel are available to perform image processing functions

There are several advantages to integrating ADAR-based mapping within a habitat mapping and monitoring program. First and foremost, the vertical imaging perspective from an airborne platform is the only practical means for conducting a wall-to-wall sample of habitat reserves and reserve systems. This, combined with the capability of synoptically viewing all canopy and exposed substrate features at nearly a single instant in time, is complimentary to the more precise and certain observations made at ground-level with lesser spatial coverage. Many of ADAR's benefits derive from the digital nature of its data, permitting image processing, enhancement, and classification through computer-assisted procedures. The spatially-explicit GIS comparability of the data facilitates its integration with other spatial data sets and use in spatially explicit models. The unclassified nature of raw ADAR data further facilitates its use in multiple applications requiring alternative classification scenarios. Finally, the repeatability of ADAR-related procedures (from data collection through pre-processing and classification) offers the potential for cost-effective monitoring of changes in habitat over time and in the long-term.

3.3.1.4 Recommendations

Results of this study indicate at least three important areas for further research.

- Apply image processing and classification techniques to other habitat types, such as conifer forest, and other woodland and upland plant communities. This would broaden the utility of ADAR and extend its applicability to additional habitat preserves in other geographical regions of California.
- Establish a long-term change detection study to further define and refine ADAR's valuable change detection capabilities. Such a study could readily build on the time-series of ADAR image data initiated through funding for the present research. Research objectives would be to identify categories of long-term changes in habitat that can be detected using ADAR, as well as to augment change detection procedures.
- Identify ADAR image attributes that correspond to habitat quality. This research task relates to a very important function for habitat management, i.e., monitoring changes in quality of habitat (as distinct from changes in habitat type). Sufficient correlation has not been established between on-the-ground characteristics that determine habitat quality and corresponding features detectable on ADAR imagery.

All three of these research topics would significantly advance ADAR's utility in areas that, based on results of this study, ADAR technology offers the most promise for realizing its cost-effective potential.

For more information on this Research Task Component, see Appendix IX.

4.0 RESEARCH PROGRAM OVERVIEW

4.1 Raptor Protection Research

This raptor protection research task had three specific goals:

- Identify the level of raptor mortality occurring in selected raptor concentration areas of SCE's service territory.
- Identify factors that could be influencing raptor perching behavior.
- Identify methods for modifying SCE's existing Raptor Protection Program to make it even more effective in minimizing risk to raptors that utilize our facilities.

4.1.1 What Did We Learn?

In the western United States, with its large expanses of desert, grassland and scrub habitat, and trees, which can serve as natural substrate sites for raptors, are rare. As a result of these conditions, raptors will utilize electric utility facilities, principally transmission and distribution-line structures (this includes wooden and metal poles and lattice steel towers) as perch and nest sites. Additionally, raptors have demonstrated that they will selectively use these poles as perch and nest sites. Raptor selection of these preferred poles is often based on prey availability, habitat types, availability and proximity of natural substrate perch sites (e.g., trees, rock outcrops, etc.), topography, wind direction, etc.

By perching or nesting on these facilities, raptors place themselves in close proximity to energized conductors, which can result in injury or death as a result of electrocutions. As long as there are raptors and power lines, electrocutions will occur. It is impossible to totally prevent raptor electrocutions. However, efforts should and are being expended to minimize the number of electrocutions. It is not feasible, cost-effective, nor necessary to modify all poles to make them raptor-safe. With over 1.4 million poles in SCE's system alone, the cost of modifying all these poles would be extremely high. If expanded to the entire western United States, the cost for modifying all poles could exceed several billion dollars.

The key to this effort, then, is to find a cost-effective approach to identify the preferred poles so that they can be made safe. . Only those poles that are preferred perch sites, located in an area where large numbers of raptors occur, and considered unsafe, need to be modified.

We have learned from this research task that raptor electrocutions appear to be a relatively rare event on SCE's electric distribution and subtransmission line system in the San Jacinto and Owens Valley. Both of these areas are known to support high numbers of raptors during certain times of the year. While these electrocutions are a source of concern for SCE, they do not appear to be biologically significant.

The efforts at identifying preferred perch sites for raptors are more complex. It does not appear that one factor or set of factors can be readily established to identify those poles which raptors prefer to perch on. Pole design seems to have little to do with perching behavior. Factors related to prey obtainment seem to be more important in determining a raptor's selection of perch sites. Prey availability and density will fluctuate from site to site and from year to year, further confounding the ability to identify preferred raptor perch sites.

4.1.2 Benefits of This Task

The information gathered from this research task has been beneficial in that the need to modify large numbers of SCE poles to make them safe for raptors does not appear necessary. This information can be used by other utilities in identifying areas where high raptor concentrations occur, and attempt to quantify more accurately levels of actual mortality.

4.1.3 Improving SCE's Raptor Protection Program

This research has demonstrated that SCE's existing Raptor Protection Program is effective in minimizing impacts to raptors that utilize SCE's facilities for perching and nesting. Can this program be improved upon? The obvious answer is yes. This research has highlighted some weaknesses in the current program that if effectively dealt with will improve the existing program, yielding more effective protection for raptors on SCE's electric and transmission systems. SCE will be evaluating how to utilize this information to improve its current program. This information could be used by other utilities in California or the western United States to see if their program can be improved as well.

4.2 Multiple Species Habitat Conservation Planning

The MSHCP research task consisted of several components. Each of these components involved different endangered species and the conservation of the habitats upon which these species depend. Some of the research was in the development of educational programs (RAMAS® GIS and the MSHCP workshop). These programs offer the potential for facilitating the MSHCP process and reducing the conflicts between endangered species and economic development. Basic research on the natural history and life-table parameters of species like the California gnatcatcher can provide others with basic information needed to effectively manage the species while, once again, minimizing the potential for conflict with sound and well planned economic development. Each of these research components that made up the MSHCP research task are discussed briefly below.

4.2.1 MSHCP Workshop

In addition to the information exchange that occurred between participants at the workshop, results of the workshop are being made available to others so that they may benefit from the significant knowledge and insight of the workshop participants. This will be accomplished by printing a synopsis of the workshop as a chapter in a book on Mediterranean ecosystems being authored by one of the workshop participants, Dr. Peter Bowler. Additionally, individual presentations from the workshop participants are being printed as a special supplement to the journal Environmental Management.

The workshop was helpful in pointing out that development of MSHCPs is no simple process. A cookbook approach must be avoided, as individual species and geographic locations require that the MSHCP be tailored to a specific area and set of circumstances. There was general consensus that more attention needs to be paid to the adequacy of scientific principles in designing, planning, and maintaining preserves established as a result of an MSHCP. Significant attention also needs to be paid to assessing the success of MSHCPs to ensure that they fulfill minimum success criteria. Without monitoring of these success criteria to determine whether the MSHCP is successful, compliance with the Endangered Species Act cannot be achieved, and the overall goals for preserving species embodied in the Act remain unfulfilled.

Recommendations for improving MSHCPs were also identified in the workshop. These recommendations include revising the U.S Fish and Wildlife Service's HCP handbook, as it was generally agreed to be too vague and did not provide adequate guidance. The role and goals that PVAs play in MSHCP development needs to be better identified. A greater diversity of expertise needs to be fully engaged in development of MSHCPs. Traditionally, most expertise involved in planning and developing MSHCPs has involved biologists. With the integration of MSHCPs into the existing developed environment in California, additional expertise is needed in order to determine the role that these external factors exert on MSHCPs and how they should be considered in the planning process.

4.2.2 Population Dynamics, Dispersal and Demography of California Gnatcatchers in Orange County, California (1998 Progress Report)

Acquisition of data on the distribution, ecology, and population dynamics of selected plant and animal species is an important objective of the designing of regional reserves that will ensure the long-term viability of rare and declining habitat types. Development of MSHCP preserves, if successfully designed and implemented, may potentially halt the decline of sensitive species dependent on the habitats being preserved, obviating the need for future listings of species, and avoiding the cumbersome regulatory framework afforded by endangered species laws.

The data acquisition of this project has provided valuable information on the status of the California gnatcatcher, enabling MSHCP planners (in this case working under the auspices of the Natural Community Conservation Planning (NCCP) program) to better understand natural history of this key coastal sage scrub species. By better understanding this species, better decisions can be made on how to plan for future preserves and to more effectively manage existing and future preserves.

4.2.3 Conservation and Management of Coastal Sage Scrub

This research effort is related to the research in 4.2.2. Data gathered from this latter task was used in this research task to update the previously developed California Gnatcatcher model. The model is a spatially explicit, stage-structured, stochastic model of the California gnatcatcher in central and coastal Orange County. At the population level, the model incorporated demographic data on survival, reproduction, and environmental variability for each population inhabiting a habitat patch. The model was implemented in RAMAS® GIS 3.0, which is designed to link landscape data from a geographic information system with a metapopulation model.

As noted in the discussion for the MSHCP workshop, sound science must be employed to help ensure the success of the MSHCP preserve. Without these scientific data, the success of the preserve cannot be ensured. The model developed as part of this research task component will be useful in providing the information necessary to help ensure that existing and future preserves are designed and maintained consistent with best management practices for the species.

4.2.4 RAMAS® Ecological Risk Model for the Desert Tortoise

The desert tortoise continues to be a species of major concern for SCE since so much of our 50,000 mi^2 service territory is within the range of the desert tortoise. Obviously, healthy populations of this species mean that it does not need the critical attention a listed species receives when it becomes listed under state or federal Endangered Species Act. SCE has played an active role in helping to ensure the continued survival of healthy populations of the desert tortoise.

The goal of this research was to build an assessment tool for the evaluation of the population-level risks to the desert tortoise from utility line siting or modification, or from maintenance operations associated with transmission lines within the range of the desert tortoise. Factors effecting the long-term viability of the tortoise were specifically examined.

The analysis suggests that even without additional impacts from transmission line siting or operation and maintenance, tortoise populations will continue to decline throughout most of their range. This ecological risk assessment is a useful management tool that will allow for enhanced monitoring capability of desert tortoise throughout its range, and lead to more effective management of the species.

4.2.5 The Metapopulation Model as an Education Tool: Providing Internet Access to RAMAS® GIS Software

A key to successful implementation of MSHCPs is education, not only sharing information on how to develop MSHCPs, but also scientific information and tools for how to use some of this information. This research task component does this. It has taken a version of the RAMAS® GIS software and made it available on the Internet so that others can access it and see how data can be used, and be aware of the factors considered in species and population management. This task is directly related to the Population Dynamics, Dispersal and Demography of California Gnatcatchers in Orange County, California, Conservation and Management of Coastal Sage Scrub and RAMAS® Ecological Risk Model for the Desert Tortoise research task components as information from these tasks were used as examples on the web site to show how this program works.

4.2.6 Comparison of IUCN and USFWS Classifications of Threatened Species

A determination of the status of species in order to assess the need for protection under state and/or federal law is very important, as this helps to determine the level of protection that a species is afforded. Depending on what a species' legal status is, it can also determine the level of attention that a species receives in its management, and whether special funding will be available to help in the management and conservation of the species. Conversely, if the status of a species is incorrectly assessed, and it does not receive the protection that its condition warrants, a species may be allowed to decline to a point where recovery is much more difficult and expensive to implement. It may even end up past the point where recovery of the species is a reasonable expectation.

The IUCN and the USFWS have developed their own classification schemes to assess the status of various species. If both of these classification schemes were based entirely on good scientific data and principles, one would expect relatively good correspondence between the two schemes. This research task has demonstrated that there is a low correspondence between the USFWS and the IUCN classification schemes. The primary reason for this is the inconsistent use of biological criteria and a heavy reliance on qualitative variables by the USFWS.

This information is important because it indicates that the needs for certain species may be misdirected, with some species receiving protection, management attention, and funding that their condition does not warrant. This information is also helpful within the context of other MSHCP research task components, since the need to set up a preserve and the information relied upon for doing that should be based on the need of the species. Targeting the wrong species in the development of these MSHCP preserves can be counter-productive to the overall success of the preserve, and it can result in a diversion of resources to the wrong species, away from more critical needs of other species.

4.3 California Habitat Evaluation

This research task focused on the use of ADAR to assess critical California habitats. Specifically accomplished in this research task was the development of methodologies for utilizing ADAR to assess and monitor various habitat types in California. The ability to carefully, quickly, and efficiently monitor habitats within MSHCPs is important in the overall management of MSHCP preserves. Without good quality data to assess how management practices are working to affect trends for species, the potential exists that the preserve and the associated species can be mismanaged or not managed effectively.

The ADAR system provides a mechanism for quickly and effectively assessing the status of habitats within a preserve and determining the overall trend, as well as determining whether specific management intervention is required. There is no question as to whether the ADAR system presents specific advantages over more traditional monitoring techniques, because it does. It provides a higher resolution of habitat data, and a more diverse assemblage of data than traditional techniques (e.g., aerial photography with ground verification). However, the question of whether it is cost-effective is unclear. To a large extent, the determination of whether the use of ADAR is worth the extra expense is going to be determined on a case-by-case basis, and will depend on the overall needs for management of the preserve and/or species in question.

4.4 Summary

The Habitat and Species Protection Research program involved a number of research tasks. Some of them, while seeming dissimilar, are in fact very much related. All of the tasks have the ultimate goal of protecting endangered and otherwise sensitive species and their associated habitats in southern California, particularly in relation to the siting and operation and maintenance of electric utility transmission lines. The results of these research tasks have yielded some valuable information and insight as to the effective management of these sensitive resources; not only in SCE’s service territory, but in other portions of California as well. This information is of benefit to SCE and the electric ratepayers of California alike.

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ETS05
Appendix I

Southern California Edison Company
Environmental Affairs Division
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Assessing Powerline Use and Electrocutions by Raptors

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INTRODUCTION

Southern California Edison Company operates electrical generation, transmission, and distribution facilities in a diverse service area that extends from rural/undeveloped Fresno and Mono counties in the Sierra Nevada to urban Los Angeles/Orange counties to the south. A majority of this service area is comprised of rural agriculture lands or natural vegetation. These areas support a variety of wildlife species, including numerous raptors.

Utility powerpoles attract raptors for numerous reasons (Bevanger 1994). Primarily, they provide perches from which nocturnal and diurnal species can hunt, feed, and sometimes nest. While raptors benefit from the distribution and number of these artificial perches, some birds are killed by electrocution due to hazards associated with these facilities (Bensen 1981; Kochert and Olendorff 1999; Olendorff et al. 1981; Williams and Colson 1989; Miller et al. 1975). Williams and Colson (1989) identify 17 species of raptors electrocuted in the western United States.

Raptor protection measures are sometimes incorporated into the permitting and licensing requirements placed upon the utility industry for new transmission projects. In addition, SCE has implemented its own Raptor Protection Program which has been in use since 1986. This program is designed to identify problem areas or poles so that appropriate modifications can be made, and to monitor raptor electrocutions system-wide. Poles associated with electrocution events, or suspected of causing them, are modified to make them safe and to discourage raptors from perching on them.

The causes of raptor electrocution are well documented (Olendorff et al. 1981; APLIC 1996). Large size is by far the most crucial factor for certain species because of the likelihood of spanning conductors with outstretched wings or other body parts. Most electrocution events occur on distribution lines rather than high-voltage transmission lines (Olendorff et al. 1981). The frequency of electrocutions is believed to be highest in areas where raptors congregate in response to prey availability.

In the SCE service area, several regions support relatively large concentrations of raptors, especially during the fall and winter months (Figure 1). The purpose of this research project was to characterize and quantify raptor use in two of these raptor concentration areas.

To fully assess the risk of electrocution by raptors, one needs to determine two values for the same area in the same period. These values are some index of raptor use and the number of raptor deaths that occurred within that sample.

Raptor use is easily quantified using roadside surveys of raptors perched on powerpoles. This provides a determination of species occurrence and their relative frequencies to one another.

Raptor fatalities are quantified by searching for dead birds under distribution lines. Since not all dead raptors are the result of electrocutions, it is important to use necropsies to verify the cause of death.

By examining and combining the results of these two field surveys, conducted concurrently with one another, it was possible to assign a relative risk assessment value that can be used for various comparisons. The level of effort directed at locating raptor fatalities was comparable between the two study areas. The risks of electrocution in two study areas within the SCE service area were then compared. This approach can also be used to assess the risk of electrocution on lines that have been modified. For example, it may be important to know if a program designed to reduce electrocutions is effective or not. To do so would require a simple comparison of the pre-treatment risk assessment value with that of the post-treatment value. A declining risk value would presumably indicate that the power line modifications were, in fact, effective at reducing raptor electrocutions. Without such data, the effectiveness of power line modification programs are unknown.

STUDY AREAS

In the San Jacinto Valley, Riverside County, 35.1 miles of roadside survey routes were established (Figure 2). Surveys in this study area included a total of 1,802 powerpoles. These surveys were not contiguous, but represented an intensive survey of the powerpoles in a particular region of the SCE service area known to support raptor concentrations during portions of the year (Thelander 1999; P. Bloom and C. Thelander,unpubl. data).

In the Owens Valley, Inyo County, another known raptor concentration area, 72.8 miles of roadside survey routes were established (Figure 3). Surveys in this study area included a total of 1,679 powerpoles. As in the San Jacinto Valley study area, these survey routes were not contiguous due to road accessibility. They represented, however, a significant portion of the power line population in the area being surveyed.

In both study areas, the survey routes were selected for their proximity and access to distribution power lines that traverse the areas. This included roads ranging from highways to dirt maintenance roads, or segments where walking was required. The length of the routes was primarily determined by the number of poles that could be thoroughly surveyed on foot for dead raptors at a sampling rate of twice per month.

METHODS

Initially, each study area was visited to establish the raptor use survey routes and to define the pole locations to be included in the surveys. Once the routes were established, the same poles were surveyed during each sampling event. All poles included in the surveys were inventoried, and characterized by type based on their line and insulator installations. All were distribution lines; no transmission lines are included. Each powerpole type was assigned an alpha-numeric code for use on data collection forms.

Each of the survey routes were subdivided into numerous segments and assigned numeric codes that coincided with road intersections, changes in power line direction, or some other obvious landmark or physical feature. Within each segment, each powerpole was assigned a unique identification number. This segmentation helped maintain accuracy in assigning pole numbers during data entry and in navigating the complex survey route.

While the approach to the research in each of the two study areas was generally the same, the field effort applied in the San Jacinto Valley was more intensive than that applied in the Owens Valley.

The San Jacinto Valley research was designed and underway by October, 1997. The first survey period was from October, 1997 through March, 1998. The second survey period was from November, 1998 through March, 1999.

BRC initiated the Owens Valley research during February-April, 1998. SCE funded the second survey period from November 1998-March 1999.

Roadside raptor counts are a widely used survey method for determining species occurrence and relative abundance. Since the focus of the study was on raptor use of powerpoles, data collection was limited to only raptors perched on powerpoles. Flying raptors were not included in the counts nor raptors perched on other features (e.g. trees).

There were two separate survey periods in each of the two study areas. In the first survey period in each study area, intensive roadside raptor counts were conducted to quantify raptor use of powerpoles. These surveys were done independently (on separate days) from the fatality searches.

In the second survey period in each study area, less intensive roadside raptor counts were conducted. In these surveys, only those raptors observed on powerpoles were recorded while the continuing raptor fatality surveys were conducted. A priority was placed on surveying for electrocuted raptors since this was the most time consuming task, and the primary focus of our research effort. Therefore, the raptor-powerpole use results for the two samples in each study area are not directly comparable.

Fatality searches required a combination of driving slowly and walking along the survey routes to visit each powerpole. The raptor fatality survey methods used in all study periods and in both study areas remained comparable throughout the study.

Electrocuted raptors typically are found at the base of powerpoles. They die immediately and fall to the ground. Therefore, a minimum area around each pole, five meters radius, was searched for the presence/absence of dead birds. In most areas, a much larger area was easily surveyed since vegetation was usually sparse or non-existent.

When evidence of a bird was present, a standardized set of data was recorded onto a field form. Field inspections were conducted for causes of death. When whole carcasses were found, they were taken to a qualified veterinarian for necropsy.

One additional (non-survey) study objective was to evaluate the reporting procedures used in SCE's Raptor Protection Program. To do this, raptor fatalities encountered in the field were compared with data reported within SCE's computer database of power outages and causes.

Also, interviews were conducted with maintenance personnel responsible for reporting and investigating raptor electrocutions and other system outages in each of our study areas.

Raptor Mortality Surveys- The field work was scheduled to ensure that every powerpole was surveyed twice per month for dead raptors. The San Jacinto Valley survey routes were surveyed twice per month in October 1997 through February 1998. One survey was completed in March 1998. They were again surveyed in November 1998- February 1999 (n= 11 surveys; 4.5 months represented).

The Owens Valley routes (n= 4) were surveyed twice per month in February and March, 1998, and once in April 1998. The routes were surveyed twice per month in November 1998- February 1999. A single (final) survey was completed in March 1999. Therefore, a total of 14 surveys were completed(7 months represented) in the Owens Valley.

Raptor Use Surveys- Each raptor use survey consisted of one (sometimes two) observer(s) driving along the predetermined route(s). Generally, they traveled roads at a safe rate of speed suitable for observing and identifying to species any raptor perched on a powerpole. They recorded every raptor (except American kestrels and common ravens) observed perching on a powerpole. The pace of the survey was dictated by the frequency of raptors along the route. The observers stopped when necessary to ensure a complete census of every pole. When the situation required it, a spotting scope was used to make accurate species identifications.

All surveys began in the morning, usually by 0730 hrs, and ended before 1100 hrs to maximize the number of observations of perched raptors. Starting points along the survey routes varied randomly. The sampling schedules were maintained regardless of weather conditions.

Each perching raptor observed was recorded as a single event. All data was recorded in the field using standardized forms. These data were then transferred to electronic databases using Microsoft Excel software.

The raptor use form included data fields for: date, route, observation number (sequential per day), species observed, survey segment, pole number, pole type, location on pole, the predominant habitat type adjacent to the pole, weather, wind, and other comments.

RESULTS

In the San Jacinto study area, from 6 October 1997 to 15 March 1998, 92 raptor use surveys were completed (East Route, *n*=56; South Route, *n*=36). The second set of surveys occurred between 1 November 1998-15 March 1999. These surveys were conducted incidental to the fatality searches, which progressed at two surveys per route per month.

In the Owens Valley study area, from 1 February 1998 to 16 April 1998, 36 raptor use surveys were completed in the Owens Valley study area. The study area is divided into four routes (Chalfant, n= 7; Laws, n= 15; Round Valley, n= 10; Mill Pond, n= 4). A second set of surveys were conducted that were incidental to fatality searches (see above) between 1 November 18 and 15 March 1999. No records were kept of incidental raptor observations during the initial November surveys.

Raptor Fatalities- Table 1 summarizes the twelve raptor fatalities found in the Owens Valley study area. Of these, six died of unknown causes. Several may have died by illegal shooting. All of these occurred in the Five Bridges/Laws area north of Bishop. The cause of death in Nos. 6-9 could not be determined due to scavenging. This area has had problems with shooting of raptors (Tom Paulek, CDFG biologist, pers. comm.). No. 12 was a common raven, a species not included in the use surveys. Therefore, six of the 12 fatality events were included in the analysis of electrocution during the survey period.

Table 1. Summary of raptor fatalities found in the Owens Valley study area.

Event	Species	Area	Date Found	PoleType	Cause
1	Great Horned Owl	Chalfant	13-Feb-98	2-Phase/CRNR	Electrocution
2	Golden Eagle	Round Valley	16-Feb-98	3-Phase	Electrocution
3	Red-tailed Hawk	Laws	25-Feb-98	3-Phase	Unknown
4	Red-tailed Hawk	Laws	3-Mar-98	3-Phase	Electrocution
5	Red-tailed Hawk	Chalfant	13-Mar-98	3-Phase (2x)	Probable Electrocution
6	Red-tailed Hawk	Laws	13-Mar-98	3-Phase	Unknown
7	Ferruginous Hawk	Laws	13-Mar-98	3-Phase	Unknown
8	Red-tailed Hawk	Laws	13-Mar-98	3-Phase	Unknown
9	Rough-legged Hawk	Laws	13-Mar-98	3-Phase	Unknown
10	Golden Eagle	Laws	1-Apr-98	3-Phase	Electrocution
11	Red-tailed Hawk	Laws	4-Jan-99	CRNR CPLX	Probable Electrocution
12	Common Raven	Laws	17-Feb-99	CRNR CPLX	Unknown

Table 2 summarizes the seven raptor fatalities found in the San Jacinto Valley study area. Nos. 1 and 2 were old carcasses of birds that died before surveys began. Nos. 3 and 4 were unusual in that both birds were found together laying on their backs. A necropsy revealed no known cause of death. There was no evidence of electrocution. Fatality Event No. 5 had scorched wing feathers. No. 6 was found fresh but the necropsy revealed no known cause of death. No. 7 was of an old carcass (bones only) that was uncovered by recent rains. Therefore, only one verified electrocution occurred in our study area during the course of our surveys. It is likely, however, that some of the others found were electrocuted prior to our surveys.

Table 2. Summary of raptor fatalities in the San Jacinto Valley study area.

Event	Species	Area	Date Found	PoleType	Cause
1	Red-tailed Hawk	South	16-Oct-97	3-Phase Complex	Unknown
2	Red-tailed Hawk	East	23-Oct-97	4-Insulators	Electrocution
3	Red-tailed Hawk	East	23-Jan-98	4-Insulators Complex	Unknown
4	Red-tailed Hawk	East	23-Jan-98	4-Insulators Complex	Unknown
5	Golden Eagle	East	26-Feb-98	3-Phase (2x)	Electrocution
6	Red-tailed Hawk	East	23-Nov-98	3-Phase (2x)	Unknown
7	Red-tailed Hawk	Eastt	28-Jan-99	3-Phase (2x)	Unknown

Raptor Use of Powerpoles- Tables 3 and 4 summarizes the results of the intensive raptor perching surveys in the San Jacinto Valley and Owens Valley study areas. Table 5 and 6 summarize the results of incidental raptor perching observations made during fatality searches. Though these two methods varied greatly, the results were surprisingly similar.

Red-tailed hawks were the most commonly observed species during all surveys. The San Jacinto Valley supports a wide diversity of raptors during the winter months. Despite this diversity, the raptor fatalities included all red-tailed hawks, except for one golden eagle.

Species diversity was lower in the Owens Valley than in the San Jacino Valley, as was the overall frequency of occurrence. The number of raptors per survey per pole in the San Jacinto Valley equals 0.0170. This same value for the Owens Valley equals 0.0095. This comparison indicates that the likelihood of a raptor using a powerpole in the San Jacinto Valley is approximately twice (+78%) that of the Owens Valley.

Raptor Electrocution Risk- The risk of electrocution is very low in both of the study areas surveyed. Of the 12 fatalities found in the Owens Valley study area, four were excluded from the analysis due to the age, species, or condition of the carcasses. Two additional fatalities listed as probable electrocutios were included, since electrocution could not be entirely excluded as a cause of mortality. For purposes of this analysis, it was assumed that at least six electrocutions occurred during the period of the surveys (n= 7 months). Based on this assumption, the fatality rate was approximately 0.86 electrocution events per month.

In the San Jacinto Valley study area, it was assumed that three of the seven fatalities found occurred prior to the surveys (n= 11.5 months). It is believed one fatality was definitely associated with electrocution and one probably associated. This yields a fatality rate of approximately 0.174 electrocutions per month during the course of the surveys.

To compare the electrocution rates in the two study areas, each fatality rate was indexed to the number of poles included per study area. This value is called the fatality risk index.

Despite the higher use of powerpoles by raptors in the San Jacinto Valley, risk of electrocution was higher in the Owens Valley study area. In the San Jacinto Valley study area, the fatality risk index is 0.00010 electrocutions per month per surveyed pole (n= 1,802 poles). The comparable fatality risk index for the Owens Valley study area is 0.00048 electrocutions per month per surveyed pole (n= 1,679). Therefore, the data indicate that the likelihood of a raptor electrocution occurring at a powerpole in the Owens Valley is 4.8 times greater than in the San Jacinto Valley.

The reason for this difference is presumably due to a relatively large number of high-risk conductor configurations being present in the Owens Valley.

Table 3. Summary of raptor use of powerpoles in the San Jacinto Valley study area from October 1997-March 1998.

	Oct. 1997			Nov. 1997			Dec. 1997			Jan. 1998			Feb. 1998			Mar. 1998				Obs.	Relative
	E	**S**	**Total**	**E**	**S**	**Total**	**E**	**S**	**Total**	**E**	**S**	**Total**	**E**	**S**	**Total**	**E**	**S**	**Total**	**Sum**	**Per Surv.**	**Frequency**
Red-tailed Hawk	306	172	478	442	136	578	378	155	533	327	66	393	229	71	300	94	24	118	2400	26.09	85.0%
Ferruginous Hawk	11	4	15	30	7	37	34	6	40	33	7	40	24	4	28	4	0	4	164	1.78	5.8%
Prairie Falcon	8	8	16	24	7	31	22	5	27	18	2	20	11	1	12	0	0	0	106	1.15	3.8%
Golden Eagle	7	1	8	11	1	12	8	0	8	6	0	6	3	0	3	0	0	0	37	0.40	1.3%
Peregrine Falcon	1	0	1	1	0	1	4	0	4	0	0	0	14	0	14	6	0	6	26	0.28	0.9%
Osprey	3	0	3	4	0	4	4	0	4	4	0	4	1	0	1	6	0	6	22	0.24	0.8%
Turkey Vulture	8	0	8	6	0	6	0	7	7	0	0	0	0	0	0	0	0	0	21	0.23	0.7%
Red-shouldered Hawk	5	1	6	5	0	5	3	0	3	0	0	0	1	0	1	0	0	0	15	0.16	0.5%
Black-shouldered Kite	1	0	1	4	1	5	5	0	5	1	0	1	1	0	1	0	0	0	13	0.14	0.5%
Merlin	0	0	0	0	0	0	0	1	1	0	1	1	4	0	4	1	0	1	7	0.08	0.2%
Cooper's Hawk	0	0	0	0	0	0	1	1	2	1	0	1	2	0	2	0	0	0	5	0.05	0.2%
Northern Harrier	0	0	0	2	0	2	1	0	1	0	0	0	1	0	1	0	0	0	4	0.04	0.1%
Sharp-shinned Hawk	0	0	0	1	0	1	0	0	0	0	0	0	1	0	1	0	0	0	2	0.02	0.1%
	350	**186**	**536**	**530**	**152**	**682**	**460**	**175**	**635**	**390**	**76**	**466**	**292**	**76**	**368**	**111**	**24**	**135**	**2822**	**30.67**	

Table 4. Summary of raptor use of powerpoles in the Owens Valley study area from 1 February – 16 April, 1998.

	February 1998					**March 1998**					**April 1998**						**Observations**	**Relative**
	CF	**LW**	**RV**	**MP**	**Total**	**CF**	**LW**	**RV**	**MP**	**Total**	**CF**	**LW**	**RV**	**MP**	**Total**	**Sum**	**Per Survey**	**Frequency**
Red-Tailed Hawk	12	12	3	3	30	5	12	5	2	24	1	4	4	2	11	65	13.0	81.3%
Swainson's Hawk											5				5	5	1.0	6.3%
Prairie Falcon		1			1	1	1			2						3	0.6	3.8%
Osprey							2			2						2	0.4	2.5%
Rough-legged Hawk							1	1		2						2	0.4	2.5%
Ferruginous Hawk		1			1											1	0.2	1.3%
Golden Eagle							1			1						1	0.2	1.3%
Great Horned Owl							1			1						1	0.2	1.3%
	12	**14**	**3**	**3**	**32**	**6**	**18**	**6**	**2**	**32**	**6**	**4**	**4**	**2**	**16**	**80**	**16.0**	

Table 5. Relative frequency of raptors in the San Jacinto Valley study area from November 1998-March 1999. Data collected incidental to fatality searches.

	November 1998			**December 1998**			**January 1999**			**February 1999**			**March 1999**				**Relative**
	E	**S**	**Total**	**E**	**S**	**Total**	**E**	**S**	**Total**	**E**	**S**	**Total**	**E**	**S**	**Total**	**Sum**	**Frequency**
Red-tailed Hawk	46	16	62	24	18	42	28	21	49	42	20	62	9	5	14	229	78.4%
Ferruginous Hawk	3	0	3	1	0	1	4	2	6	6	1	7	1	0	1	18	6.2%
Golden Eagle	3	0	3	2	0	2	2	0	2	2	0	2	0	0	0	9	3.1%
Peregrine Falcon	2	0	2	0	0	0	1	0	1	3	0	3	0	0	0	6	2.1%
Northern Harrier	3	0	3	1	0	1	1	1	2	0	0	0	0	0	0	6	2.1%
Prairie Falcon	2	0	2	0	1	1	0	1	1	1	0	1	0	0	0	5	1.7%
Black-shouldered Kite	2	0	2	1	0	1	0	1	1	0	0	0	0	0	0	4	1.4%
Merlin	0	0	0	0	1	1	1	1	2	0	1	1	0	0	0	4	1.4%
Osprey	0	0	0	2	0	2	0	0	0	0	0	0	0	0	0	2	0.7%
Turkey Vulture	0	2	2	0	0	0	0	0	0	0	0	0	0	0	0	2	0.7%
Cooper's Hawk	1	0	1	0	0	0	0	0	0	0	0	0	0	1	1	2	0.7%
Sharp-shinned Hawk	0	1	1	0	1	1	0	0	0	0	0	0	0	0	0	2	0.7%
Swainson's Hawk	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2	0.7%
Red-shouldered Hawk	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	1	0.3%
	62	**19**	**81**	**31**	**21**	**52**	**38**	**27**	**65**	**54**	**22**	**76**	**10**	**8**	**18**	**292**	

Table 6. Relative frequency of raptors in the Owens Valley study area from November 1998-March 1999. Data collected incidental to fatality searches.

	November 1998					December 1998					January 1999						February 1999					March 1999					Relative
	CF	**LW**	**RV**	**MP**	**Total**	**CF**	**LW**	**RV**	**MP**	**Total**	**CF**	**LW**	**RV**	**MP**	**Total**	**CF**	**LW**	**RV**	**MP**	**Total**	**CF**	**LW**	**RV**	**MP**	**Total**	**Sum**	**Frequency**
Red-Tailed Hawk		2			2		3	5		8	9	15	9		33	8	6	6		20	5	5	9		19	82	79.6%
Prairie Falcon					0	5				5					0	3	2	1		6	1		1		2	13	12.6%
Rough-legged Hawk					0					0					0	1	1	1		3					0	3	2.9%
Ferruginous Hawk		1			1					0					0		1			1					0	2	1.9%
Cooper's Hawk					0					0					0	1				1			1		1	2	1.9%
Golden Eagle					0			1		1					0					0					0	1	1.0%
	0	**3**	**0**	**0**	**3**	**5**	**3**	**6**	**0**	**14**	**9**	**15**	**9**	**0**	**33**	**13**	**10**	**8**	**0**	**31**	**6**	**5**	**11**	**0**	**22**	**103**	

DISCUSSION

Raptor use of powerpoles cannot be accurately predicted by simply evaluating a pole's particular configuration, or its location on the landscape. However, it is widely accepted that raptor use of power poles is based on pole location, habitat diversity, and availability of prey (Pearson 1979). Predicting raptor electrocutions is even more difficult. The present study demonstrates that raptor electrocutions occur at differing rates throughout the SCE service area. Also, the rate of raptor electrocutions is disproportionate to raptor use. For example, it was determined that in the Owens Valley, where raptor use was lower than in the San Jacinto Valley study area, the likelihood of an individual raptor being electrocuted was nearly five times greater.

Numerous environmental and behavioral factors unrelated to the physical characteristics of the poles almost certainly dictate whether or not raptors use a particular pole. In some cases, raptor use is species-specific. For example, some powerpoles (or lines of powerpoles) occur in areas where prey favorable to golden eagles occurs in numbers that attract this particular raptor species. Nearby, other poles with seemingly the same physical configuration may not attract golden eagles as perch sites because the prey they seek is not visible or present.

Other factors that might predict raptor use include habitat conditions, topographic features, and prey vulnerability specific to each raptor species and within the hunting radius of the pole. Also, remoteness from disturbance by people and vehicles may also play an important role in raptor pole selection.

Future efforts to minimize raptor electrocutions should focus on the development of reliable predictive models that: (1) identify regions, lines, or specific poles with a high probability of raptor use by vulnerable species, and (2) identify pole line configurations that have documented raptor electrocutions associated with them. While such models are unlikely to result in pole-specific identification of potential electrocution sites, they would effectively target portions of a utility's service area that had the highest probability of electrocution occurrences. With this information, efforts to identify specific poles or lines of poles would be improved. Modifications could then be made where the probability of reduced fatalities due to electrocution was highest.

SCE's Raptor Protection Program is a useful tool for monitoring raptor electrocutions, identifying areas or individual poles needing modifications to reduce electrocutions, and for educating SCE field personnel on the proper procedures to follow when a raptor electrocution occurs.

The database of raptor electrocution information that SCE has accumulated may be useful in characterizing those power lines with the highest frequency of raptor electrocutions. Also, by quantifying the characteristics of each powerpole involved in an electrocution, it may be possible to identify particular configurations that have a high probability of resulting in an electrocution.

It is instructive to put the raptor electrocution issue into context with other energy-related population regulating factors. For example, golden eagles are killed at the rate of about 40 per year by wind energy generating facilities in the Altamont Wind Resource Area (AWRA). Hunt et al. (1998) recorded 61 golden eagle fatalities using radio-telemetry between January 1994 and December 1997. Of these, 37% were attributed to turbine strikes and 16% were caused by electrocution. Combined, these two factors represented slightly more than 50% of all golden eagle fatalities.

This level of mortality occurs within a small, 70 mi^2 area in the central Coast Ranges of California. Detailed population studies on the area's golden eagles (over 50 nesting pairs) indicate that this 'population' remains stable, or possibly declining at a very gradual rate (Hunt et al., op. cit.).

The SCE service area of 50,000 mi^2 supports a major portion of the entire golden eagle breeding range in California. The number of golden eagles reported to be electrocuted throughout the SCE service area averages less than five birds per year (Pearson, pers. comm.; SCE unpubl. data) Therefore, it is reasonable to conclude, assuming all or most raptor electrocutions are detected, that the impact of electrocutions on golden eagles is having no measurable impact on the entire golden eagle population occurring in southern California. This conclusion, however, in no way lessens the importance, or the legal obligation, of SCE continuing to make every reasonable effort to minimize the frequency of raptor electrocutions. Also, it highlights the need for accurate monitoring and detection of raptor electrocutions.

The present study demonstrates that a cost-effective approach exists for determining raptor electrocution risk in selected areas (or regions) of a utility's service area. The SCE Raptor Protection Program partially meets these requirements. To improve the program would require less reliance on internal monitoring by maintenance personnel and the adding of periodic monitoring by qualified biologists. The methods used in this study can be applied to monitoring programs designed to reduce raptor electrocutions by quantifying their effectiveness.

In summary, raptor electrocutions appear to be rare events along Southern California Edison's power distribution system in the San Jacinto Valley and in the Owens Valley. These two study areas are in areas known to support raptors in high numbers at particular times of the year. Future research in other raptor concentration areas within the SCE service area will provide additional insights and comparative information that, ultimately, may yield guidelines and recommendations that can further reduce the rate of raptor electrocutions.

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ETS05

Appendix II

An Assessment of SCE's Raptor Protection Training Program

Southern California Edison Company

Environmental Affairs Division
Rosemead, California

An Assessment of SCE's Raptor Protection Training Program

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July 1999

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Evaluating SCE's Raptor Protection Training Program

In November 1997, Southern California Edison Company (SCE) contracted BioResource Consultants (BRC) to conduct a research project on the extent of raptor electrocutions in the San Jacinto Valley, Riverside County. In 1998, that project was expanded to include the Owens Valley, Inyo County (see Thelander 1999).

The research effort involved quantifying raptor use of powerlines and comparing the frequency of fatalities (i.e., electrocutions) along those same powerlines during the same time period. It is difficult to determine the significance of the findings since no comparable results are available for similar studies. In relation to other mortality factors believed to regulate raptor populations, electrocutions appear to play a relatively minor role. This may vary, however, from region to region.

The findings showed that while raptors occurred more frequently on powerpoles in the San Jacinto Valley, the likelihood of electrocution was greater in the Owens Valley. It is believed that this difference was related in some way to the presence of particular powerline configurations that represent an increased risk of electrocution. Based on these findings, it is hoped that SCE will take the appropriate action to modify those facilitates identified as having caused the electrocutions, thus eliminating the possibility of future occurrences. In addition, by examining the characteristics of those poles it may be possible to identify other similar poles for modification in at least the two study areas involved.

SCE'S RAPTOR PROTECTION TRAINING PROGRAM

In addition to conducting the field research on raptor electrocutions, SCE requested that BRC observe and report on the procedures followed by SCE personnel regarding electrocutions and internal procedures for reporting electrocutions per established procedures. The procedures to accomplish this are established in a company-wide program called the Raptor Protection Training Program (RPTP).

Since the 1970s, SCE has taken the initiative to monitor the frequency and extent of electrocutions on powerlines it owns and operates. In 1986, SCE initiated its current Raptor Protection Training Program (RPTG) (Eakle and Gray 1989). Prior to that, SCE had experimented with a system of reporting raptor electrocutions, but no formal procedures were established or uniformly operating throughout the company. The program consisted initially of a training video, a field personnel training program presented by an SCE biologist, and training brochures that were left with the attendees.

For the past decade, the RPTP has steadily grown and expanded as an established operating procedure within SCE. Today, the RPTP is one of many procedures that are required of all field maintenance and operations personnel throughout the company. The program was designed by SCE's Environmental Affairs Division and has been distributed widely throughout the company.

This RPTP is a voluntary response to the company's need to comply with such legislation as the Migratory Bird Treaty Act, the Bald Eagle Protection Act, federal Endangered Species Act, the California Endangered Species Act, and the California Fish and Game Code. Recently, the US Fish and Wildlife Service(USFWS) has increased its enforcement actions on raptor electrocutions within the utility industry. The burden of proof regarding the extent of electrocution occurrences appears to be falling on the utility industry. This need for information highlights the importance of this evaluation of the RPTP.

While conducting the raptor electrocution research project from 1998-99, BRC had the opportunity to evaluate the effectiveness of SCE's Raptor Protection Training Program. BRC worked in the field alongside maintenance and operations personnel, coordinating research efforts with Edison's Senior Biologist (Dan Pearson), and regularly visiting SCE powerlines in search of electrocuted raptors. The report that follows summarizes BRC's findings.

BACKGROUND

The raptor electrocution problem first received widespread consideration in the U.S. following reports of nearly 1,200 bald and golden eagle deaths in Wyoming and Colorado in the winter of 1970-71. Of these, over 300 were found shot or electrocuted along power lines (Olendorff et al. 1981).

In 1972, the U.S. Rural Electrification Administration (REA) published a guide to reduce raptor electrocutions. New and safer powerline designs began to be tested. This effort led to the publication of three editions of *"Suggested Practices for Raptor Protection on Power Lines"* (Miller et al. 1975, Olendorff et al. 1981, APLIC, 1996), which provide guidelines for managing electrocution problems.

In 1989, nine major electrical utilities joined forces and formed the Avian Power Line Interaction Committee (APLIC) to study and address the problems of bird electrocutions and collisions.

Throughout this time period, SCE had developed an informal reporting and data processing system for addressing wildlife electrocution problems. In 1986, SCE formalized these procedures when it initiated the Raptor Protection Training Program. The basic goals of the RPTP include:

1- reduce negative impacts to raptors from SCE facilities;
2- ensure compliance with state and federal laws, rules, and regulations protecting raptors;
3- compile data on electrocutions on SCE facilities;
4- assist SCE biologists in identifying problem areas where raptor protection may be required;
5- improve line construction methods to minimize raptor electrocutions; and
6- help identify and isolate where bird-caused outages occur so that they can be minimized.

In 1997, Harness (1997) compiled raptor mortality records from 1986 through 1996 from 58 electric utilities located in the western U.S. This effort was one of the most comprehensive analyses of distribution line electrocutions; however, it did not include SCE facilities. The findings provide valuable insights about the extent of the problem.

Harness (op.cit.) provides data on 1,450 confirmed raptor electrocutions. Records were reviewed to determine the types of utility structures placing raptors at risk of electrocution. The most commonly reported species electrocuted were eagles, with golden eagles reported 2.3 times more frequently than bald eagles. Juvenile golden eagles were reported more frequently than adult birds. Red-tailed hawks and great-horned owls were the most commonly reported hawk and owl species. Hawk and owl electrocutions resulting in power outages were found to be elevated in late summer, probably reflective of immature/juvenile perching on poles.

Of the total mortalities, 646 were associated with specific utility construction units. Harness suggests that although transformers are relatively rare on rural overhead distribution systems, they are involved in most rural raptor electrocutions. Three-phase transformer banks were associated with a disproportionate number of detected electrocutions. These units appear to be particularly lethal to raptors because of minimal phase-to-phase and phase-to-ground separation between bare energized jumper wires connecting transformer, protective cutouts, and surge arrestors. These units may also be dangerous because they are often connected to irrigation pumps located in remote areas likely to contain high raptor populations.

Harness (op.cit.) provides recommendations that focus primarily on widespread modifications to powerpoles even when no electrocutions have been reported for those areas. While this solution may reduce electrocutions, the cost of such an effort is probably prohibitive and the likelihood of getting utilities to comply is low. Instead, it may be more feasible to identify the specific characteristics of powerpoles that contribute most to raptor electrocutions, locating those configurations within known raptor use areas, and then recommending the immediate modification of those poles. Using this focussed approach will be less costly, it will benefit the utilities by identifying locations where customer outages are most likely to occur, and it will rectify the frequency of dangerous poles in the shortest time possible.

DEVELOPING THE RAPTOR PROTECTION TRAINING PROGRAM

SCE's RPTP began in 1986, and consisted of an onsite training program by an SCE biologist, brochures, a training video, and the distribution of reporting forms. Early efforts were followed by the development of two components designed to be the building blocks of the RPTP. The first of these was a summary document entitled *Southern California Edison Company Raptor Protection Plan* (Eakle and Gray 1989). The second was a qualitative model designed to help predict areas of potential raptor electrocution (Thelander et al. 1989). The earliest objective of the RPTP was to identify specific geographic areas within SCE's

Northern Division where raptor-safe poles were needed for new or existing distribution lines. Since that time, the program has been expanded to include the entire SCE service area.

To prepare the initial plan, the authors completed a comprehensive literature review and data were assembled on the distribution, behavior, and habitat requirements of raptors within SCE's Northern Division. Interviews were conducted with knowledgeable federal and state personnel, raptor biologists, and representatives from each SCE district who were familiar with their local raptor concentrations, nesting sites, and previously documented electrocutions.

Thelander et al. (1989) explored the merits of several types of qualitative in an attempt to find a cost-effective tool for predicting raptor electrocution hazard or risk. Beginning with the premise that distribution lines have unequal potential for resulting in a raptor electrocution, this study examined the feasibility of characterizing two fundamental topics involved in conceptualizing electrocution risk.

First, these are the physical features of distribution lines that account for raptor electrocutions. These include the biotic features of the land surrounding powerlines that attract raptors for perching, foraging, and nesting. These include such things as vegetation associations, prey species requirements, and habitat diversity. Second, there are abiotic features that reflect the physical characteristics of the landscape and human disturbance elements. By identifying and characterizing several key biotic and abiotic features, the study demonstrated that a model could be developed to locate problem areas. By initially locating problem areas versus non-problem areas, the scope of the problem could be narrowed to those areas where a focussed effort to reduce electrocutions could have the greatest benefit.

The major advantages of predictive models is their proactive potential to aid in identifying problem poles, areas, and lines before electrocutions or related power outages occur. Ranking and comparisons can be made based on the relative probability of poles or lines being used by raptors, in relation to the risk of the use of resulting in an electrocution.

Seven area were identified within SCE"s service territory as areas where raptors are most likely to concentrate in fall and winter (Figure 1; P. Bloom and C. Thelander, unpubl. data). Monitoring of electrocution using periodic biological field surveys is currently being considered by SCE.

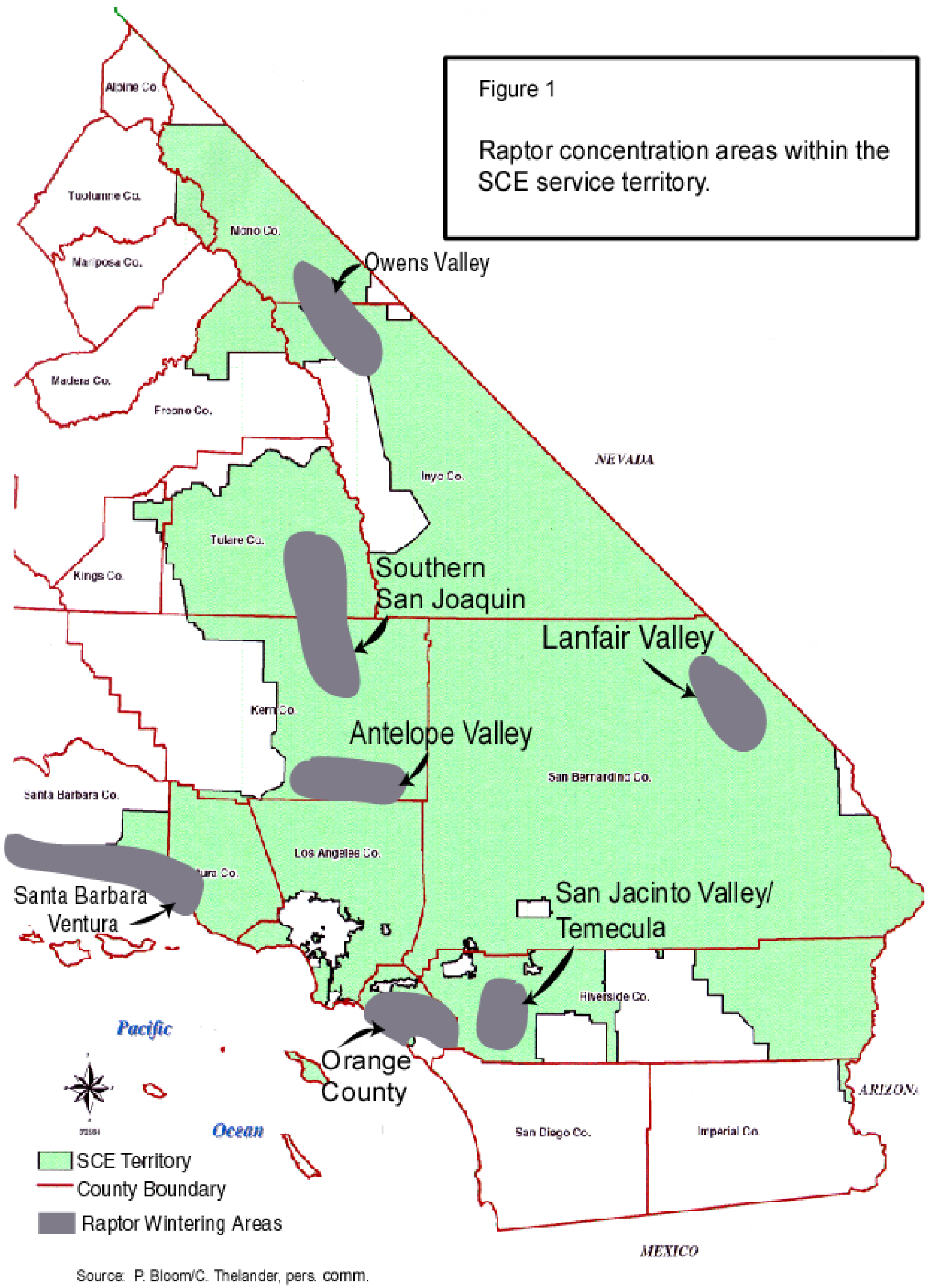

Figure 1
Raptor concentration areas within the SCE service territory.
Owens Valley
Southern San Joaquin
Lanfair Valley
Antelope Valley
Santa Barbara Ventura
San Jacinto Valley/ Temecula
Orange County
Alpine Co.
Tuolumne Co.
Mono Co.
Mariposa Co.
Madera Co.
Fresno Co.
Inyo Co.
Tulare Co.
Kings Co.
Kern Co.
San Bernardino Co.
Santa Barbara Co.
Los Angeles Co.
Riverside Co.
San Diego Co.
Imperial Co.
NEVADA
ARIZONA
MEXICO
Pacific
Ocean
SCE Territory
County Boundary
Raptor Wintering Areas
Source: P. Bloom/C. Thelander, pers. comm.

SCE's Raptor Protection Plan is a flexible program that can address new information and procedures as they are developed. This plan has remained the cornerstone of the RPTP over the past decade. Eakle and Gary's report (1989) has served SCE well. However, much new information exists about raptor natural history, distribution within the SCE service area, and there are many new ways to efficiently analyze large amounts of geographic information for planning purposes. In this evaluation, it is recommended that some of the RPTP information be updated and that SCE consider developing a GIS-approach to compiling and managing the information on electrocutions.

As mentioned above, BRC's 1997-98 raptor electrocutions research efforts focussed on just two relatively small areas within the SCE service area. The evaluation of the RPTP represents an independent perspective of how the RPTP functions under actual field conditions in two representative areas. This evaluation is not intended to be a comprehensive, company-wide critique. It is believed, however, that based on discussions with SCE employees, BRC's observations fairly characterized the overall program and that the recommendations apply to the company-wide administration of the program. Regardless, it is likely that regional differences occur and that these may represent unique circumstances not identified in this effort. Continued efforts to identify these unique circumstances may be warranted.

Overall, the RPTP appears to be an excellent example of a large and diverse corporation taking the initiative to adhere to its own environmental mandates, and the many laws that govern wildlife protection and conservation. With some minor updates, BRC recommends that the program be continued for the indefinite future.

SPECIES OF INTEREST

Williams and Colson (1989) reported that 17 raptor species had been involved in electrocutions in the U.S. SCE's Raptor Protection Plan identifies those raptor species found in California that are most prone to electrocution. These are generally the larger eagles, hawks, and owls because they more easily span the distance between energized wires on distribution lines carrying between 12kV and 69 kV.

Among the large raptors in general, those species that frequently use power poles for nesting, perching, and hunting are most likely to be subjected to electrocution. Golden eagles have been the most frequently electrocuted raptor. Most of these have been subadults (Olendorff, et al. 1981, APLIC 1996). The list of highly vulnerable species also includes the bald eagle, osprey, red-tailed hawk, ferruginous hawk, rough-legged hawk, and Swainson's hawk. Also, great horned owls and common barn owls are frequently electrocuted when they use perches on power poles and transformers.

Other species less frequently impacted include the black-shouldered kite, red-shouldered hawk, northern harrier, prairie falcon, peregrine falcon, and the short-eared owl. Several other raptors are found in the SCE service area but they are much less frequently found electrocuted. These include forest dwelling *Accipters*, smaller falcons like American kestrels and merlins, and several small owl species. Because of their smaller size, habitat requirements, and behavior, they are very rarely electrocuted.

For each of the species of concern, SCE's Raptor Protection Plan identifies seasonal distribution and concentration areas in California. Breeding golden eagles tend to be resident across most of the state, but migrants from the north also concentrate in portions of SCE's service area. During the winter months, golden eagles are more dispersed, often found in interior areas such as Antelope Valley and Cuyama Valley (Garrett and Dunn 1981). In Santa Barbara County, golden eagles have been recorded nesting in the San Rafael Mountains and the Sierra Madre, and wintering in the Santa Maria Valley and the along the Santa Ynez River (Lehman 1982). Thelander (1974) found about 25 golden eagle territories within the six counties that encompass SCE's Northern Division. Schorff (1986) found 16 territories in Kern County, one in Kings County, two in Los Angeles County, seven in Santa Barbara County, one in Tulare County, and one in Ventura County.

Bald eagles are found throughout California in winter months, but breeding pairs are generally confined to the northern part of the state (Detrich 1979). Some nesting is beginning to occur at lakes in southern California.

Wintering sites for bald eagles are generally lakes and reservoirs where eagles feed on a variety of fish species and waterfowl, including coots. Bald eagles wintering on the coast are generally found near the larger estuaries (Garrett and Dunn 1981). Several important bald eagle wintering areas in southern and central California include Millerton Lake (Madera and Fresno Counties, San Antonio/Nacimiento Reservoir (Monterey and San Luis Obispo Counties), Lake Cachuma (Santa Barbara County), Big Bear Lake (San Bernadino County), and Lake Mathews (Riverside County) (Detrich 1986).

Ospreys were found historically throughout the state, but numbers have long been greatly reduced (Grinnell and Miller 1944). This species is still found along the coast, and near freshwater lakes and streams. The osprey is primarily a summer resident in California, migrating to Central and South America in the winter. Along the coast, ospreys have been recorded as transients in the late summer and early fall. Any large coastal estuaries and inland lakes are likely to be visited by ospreys at some time of the year (Garrett and Dunn 1981). Lakes within Edison's Northern Division where ospreys are known to winter include Lake Piru (Ventura County) and Isabella Lake (Kern County). Ospreys are known to nest on Lake Kaweah, along the Kaweah River, and on Lake Casitas (Ventura County) (Remson 1978).

Red-tailed hawks are the most widespread and generalized of the Buteonine hawks found in California. They nest in a variety of habitats (Garrett and Dunn 1981, Grinnell and Miller 1944). Breeding red-tailed hawks are mostly resident, but those nesting in the northern states frequently winter in California. Wintering red-tailed hawks can be commonly found in disturbed habitats and agricultural areas.

The ferruginous hawk is the largest of the North American Buteonine hawks. It also has the smallest breeding range of any *Buteo* species widely occurring north of Mexico. In California, the hawk is known primarily as a wintering migrant, but there are a few summer records from the northeast (Palmer 1988). The ferruginous hawk typically occupies arid, semiarid, and grassland regions with level and rolling terrain or foothills. During the winter, they can be found in agricultural area, pastures, fallow fields, and other habitats where adequate prey can be found, especially ground squirrels and jack rabbits (Grinnell and Miller 1944). Important wintering localities in southern California include the Carrizo Plain, Cuyama Valley, Antelope Valley, San Jacinto Valley, and along the Santa Maria River Plain (Garrett and Dunn 1981).

Rough-legged hawks breed in the tundra and taiga regions of the world, and winter south of breeding ranges. Hawks wintering in the U.S. are found in a variety of open habitats including prairies, semideserts, open fields, marshlands, bogs, dunes, and even garbage dumps (Palmer 1988). In California, wintering rough-legged hawks are primarily found in the northern two-thirds of the state, but they have also been recorded from the Kelso Valley in Kern County, and in southern Ventura County (Grinnell and Miller 1944). They can be found locally in the Antelope Valley in open fields, grasslands, and agricultural areas. On the coast they frequent open plains and river valleys (Garrett and Dunn 1981) such as the Santa Maria Valley (Lehman 1982). Other locations of occurrence include the Cuyama Valley, Lake Cachuma, the Santa Ynez Valley, and Goleta.

Swainson's hawks inhabit semi-open to open terrain including the prairies and deserts of the U.S. and Canada. They frequently nest in shelterbelts and other tree rows within agricultural areas. In California, they were formerly very abundant, nesting in the Sacramento and San Joaquin Valleys and elsewhere in the state. Their numbers have been greatly reduced and the extent of their breeding range, due to human habitat alterations.

In SCE's Northern Division, Swainson's hawks can be observed migrating south in the fall, and migrating north in the spring (Grinnell and Miller 1944). As many as eight pairs nest in the Owens Valley. Large flocks have occasionally been noted, but these numbers have also declined historically (Garrett and Dunn 1981). An important migration corridor for this hawk and many other species is along the San Emigdio Mountains, past Grapevine and Gorman, to the San Andres Rift (Lehman 1982).

SCE's Raptor Protection Plan recognizes a number of other raptor species that are less prone to electrocution because of their size, behavior, or habitat utilization. These include the red-shouldered hawk, black-shouldered kite, northern harrier, prairie falcon, peregrine falcon, great horned owl, barn owl, turkey vultures, and others even more rarely encountered as victims of electrocution.

The Raptor Protection Plan also reviews the factors affecting the likelihood of raptor electrocution, including pole design, pole location, topography, behavior and habitat considerations of particular species, and the interaction of some of these factors. The plan proposes a protocol for use in determining priority areas for raptor protection efforts. This protocol has never been formally implemented, though other efforts were made to locate raptor concentration areas in the SCE service area.

EVALUATING THE RAPTOR PROTECTION TRAINING PROGRAM

This evaluation attempts to address four fundamental questions regarding the implementation of SCE's RPTP. In the following section, an attempt is made to address each of these questions through examples that were encountered, through discussions with SCE personnel, and by general perceptions of how the program might be improved. The evaluation incorporates a series of recommendations that are intended to be a guide for improving the RPTP in the years to come.

Are SCE field personnel aware of the RPTP, familiar with its procedures, and properly trained?

All of the SCE personnel encountered in the field were aware of the RPTP, its procedures, and their responsibility to adhere to the company's policies regarding reporting electrocutions. In both of the areas where research was conducted, SCE personnel met with BRC to discuss the project. In every case, the firsthand knowledge by SCE personnel of the program's procedures was impressive. They demonstrated their past compliance with the program by locating files containing the original Raptor Mortality Forms for the electrocutions they had encountered in their areas of responsibility.

It is possible that raptor electrocutions can go unreported due to administrative oversight. For example, if an electrocution is confirmed and a Raptor Mortality Form is completed on the event, it may be possible that the form does not get forwarded to the Environmental Affairs Division in a timely manner, or it never gets forwarded. Based on BRC's assessment, it appears that this is a rare event.

To help ensure that this does not occur, it is recommended that a biologist within the Environmental Affairs Division be assigned to review, as part of their assigned activities, each daily report of outages. If there are any indications of any wildlife-related outages, the biologist should inquire with the appropriate substation personnel to inquire about the outcome of the investigation. The frequency of wildlife-related outages is low enough that this procedure is unlikely to place an heavy burden on the biologist or the substation personnel. By doing so, there will be a better 'checks and balances' approach to ensuring that all Raptor Mortality Forms reach Environmental Affairs where they are to be compiled and analyzed.

With respect to training and circulating information about the program, it is believed that SCE has done an excellent job at on-site training regarding procedures. Only periodic updates are required, or the training of new personnel who have no experience with the RPTP.

Do the RPTP's procedures operate properly under field conditions? SCE has a dual incentive to minimize the frequency raptor electrocutions. Clearly, there is a legal mandate to ensure that no wildlife protection laws are violated by company operations. In addition, power outages result in inconvenience to SCE's customers and they result in a loss of revenue. SCE is adequately motivated to make every reasonable effort to reduce raptor electrocutions.

When a power outage is reported, SCE maintenance personnel are immediately dispatched to the location. They immediately attempt to determine the cause of the outage. There are 15 "Trouble Cause Codes" specific to wildlife, and with numeric designations, that can be used by SCE inspectors to describe the situation. For example, Code 0802 is "Raptor faulted line." When the cause is determined, the inspector reports this information to a central dispatch system. The information appears on a daily, computerized summary report. If a raptor or other bird was involved in the outage, the inspector is trained to fill out a Raptor Mortality Form, often taking a picture to verify identification, and to submit that form to SCE's Environmental Affairs Division. This system appears to be working as it was intended.

SCE field inspectors are trained and equipped to properly report the information in suitable detail to provide an accurate record of all known wildlife-caused outages. If they have any questions, they do not hesitate to call the Environmental Affairs Division for assistance. Recently, the inspectors had been told to make every effort to determine the cause of every reported outage. The company seems to be making every effort possible to determine the true cause of each power outage, and to minimize the duration of the outage and eliminate the possibility of a repeat occurrence. Both of these incentives bolster the reliability of the reporting mechanisms within the RPTP.

In most instances, when an electrocution is reported, Environmental Affairs personnel follow-up on the report to determine if future events can be avoided. It is recommended that this follow-up become a standard requirement of the procedures, if it is not already. It is SCE's current policy to modify any pole, if possible, where an electrocution is reported. In some instances, there have been no obvious means of modifying the pole to eliminate a future electrocution since it could not be determined exactly how or why the electrocution occurred. This policy was implemented in response to confirmed raptor electrocutions we became award of during the course of our research.

It is recommended that SCE consider maintaining information on the locations where configuration modifications are made to avoid electrocutions. This could easily be integrated into the overall raptor electrocution database being recommended for future use.

How might the RPTP be improved? Based on the findings presented above, the following recommendations are offered for improving upon the RPTP. It is recommended that SCE update the RPTP to incorporate new information into a GIS database. By doing so, raptor electrocution data and information on raptor occurrence and distribution can be better integrated into SCE's overall resource planning efforts.

Update the Raptor Protection Program's Documentation- It is recommended that SCE update the RPTP to incorporate new, current information on raptor use areas and related topics. These data should be maintained in one of SCE's existing GIS databases. By doing so, raptor electrocution data and information on raptor occurrence and distribution can be better integrated into SCE's overall resource planning efforts.

***Better maintenance of electrocution records*-** In February 1998, BRC was given access to a major portion of SCE's internal files of historical information on raptor electrocutions throughout its service area. These materials mainly included handwritten

Raptor Mortality Forms. These had been filled out and forwarded to the Environmental Affairs Division by substation field personnel responsible for investigating outages caused by a wide range of circumstances, including bird-related line faults. Many of these reports had Polaroid photographs attached. We converted these reports to a computerized database using Microsoft Access. An example printout of this database is provided in Appendix A. In the future, all data that is provided to the Environmental Affairs Division using the Raptor Mortality Forms should be placed into the computerized database for easy access and analysis.

The historical electrocution data provided to BRC included records of 136 raptor-related power outages. They ranged from September 1981 through March 1998. Additional historical records of raptor electrocutions probably remain to be entered into the new computerized database. SCE biologists need to locate and collect those completed Raptor Mortality forms and enter those data into the new system. Properly maintaining and using this database will result in single source for all of SCE's records on raptor electrocutions. This will be a useful tool for managing the distribution system to minimize outages due to electrocutions and in working with state and federal wildlife enforcement agencies.

Ensure that all raptor electrocutions are detected and reported- As mentioned above, it is likely that the number of electrocutions is currently being under reported. In the Owens Valley, it was noted that raptor electrocutions occurred but that the normal maintenance and operations procedures used did not detect them. Only when an electrocution causes a circuit to break do SCE personnel become aware that a problem has occurred. Several instances were found where electrocutions occurred but where there was no report of the incident. The extent of this circumstance is unknown at this time.

Roads are present under most of the distribution lines that were surveyed for raptor electrocutions. SCE maintenance crews periodically travel these roads. If they discover a dead raptor under a distribution pole, there is no requirement to report it if it has not caused a power outage. This lack of reporting on raptors found dead under poles results in an under reporting of the full extent of the electrocution problem. Conversely, raptors continue to be illegally shot while perched on powerpoles. It would be inaccurate to merely assume that every raptor found dead under a distribution line was related to an electrocution. Therefore, it is recommended that periodic monitoring be done, using field survey techniques developed by BRC (Thelander 1999). Future monitoring efforts in areas not previously surveyed would yield information on the relationship between the number of reported raptor electrocutions versus those that go unreported. Trained and qualified observers would need to make the determination of the cause of death. Blind necropsies should be performed whenever possible.

From an operations perspective, it is beyond the scope of this evaluation to recommend how best to entirely rectify the situation of under reporting electrocutions. There no doubt are trade-offs to setting the relay system's switches on selected circuits to a sensitivity that will ensure that every electrocution is detected. In fact, changing the sensitivity will likely result in more power outages for SCE customers, a result that is counter-productive to SCE's mission.

An alternative approach is to add a systematic monitoring element to the RPTP. All of the existing reporting procedures used by the substation personnel should remain in place. However, it may be appropriate

It is recommended that SCE thoroughly address this problem in the near future. Until a solution is implemented, the credibility of the RPTP may come into question by wildlife enforcement agencies since, at present, there is no accurate way to quantify the number of electrocutions that are occurring throughout the SCE service area.

Update the Raptor Protection Plan- Much can be done to improve the existing Raptor Protection Plan. For example, new information on raptor use areas within the SCE service area can be incorporated into a geographic information system (GIS) database. The existing maps are outdated and lack sufficient supporting information. Also, as future electrocutions are reported, they can be easily mapped into the GIS system. By comparing this information over time with land use and habitat elements in the database, trends and trouble spots can be readily identified. Areas can be readily identified where improvements are needed to reduce electrocutions.

Regularly monitor portions of the service area- It is recommended that each year, SCE select one or more specific areas identified in the GIS analysis of raptor use and conduct a detailed, quantitative raptor electrocution risk assessment. The methods used would closely follow the research effort just completed in the San Jacinto Valley and in the Owens Valley.

This monitoring effort will proceed incrementally from year to year. The result will be a growing baseline of information that can be used to ensure that fluctuations in the frequency of raptor electrocutions are quickly identified and dealt with properly. Having a historical database will enable SCE biologists to better evaluate the magnitude and significance of any future electrocution reports. By viewing these new data in relation to existing historical information, SCE will be better informed in its response to emergencies and to the regulatory and enforcement agencies.

Are the goals of the RPTP being met? Since 1989, raptor electrocutions have continued to occur in the SCE distribution system. It is unlikely and impractical to assume that such events can be entirely eliminated. The system is too large and too diverse. It is possible, however, to make progress toward reducing electrocutions rates to levels viewed as unavoidable or insignificant by the regulatory agencies. Implementation of the RPTP has demonstrated steady progress by SCE in its efforts to reduce the rate of electrocutions.

Increased and improved monitoring is probably the most significant improvement that needs to be made to ensure that the RPTP's goals continue to be met. This will ensure that SCE continues to comply with state and federal laws and regulations.

The RPTP could be improved by updating the information database that is relied upon to determine raptor use areas in relation to powerlines. This new information would enhance SCE's ability to maintain its proactive approach to making improvements to the system, especially where system rebuilds are underway, that will ensure that raptor electrocutions are minimized.

Overall, the RPTP remains an effective tool for identifying individual poles where electrocutions are detected. The reporting mechanisms in place generally meet the goals of the RPTP so that the proper information is communicated to SCE personnel who can implement modifications on a pole-by-pole basis. With only minor modifications, the RPTP can be improved, thus increasing its effectiveness as a useful management tool and set of field procedures.

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APPENDIX A
Example printout of SCE's raptor electrocution database.

Date	2/28/98	Time:		Duration:		Source	Raptor Fatality Fo

District:	Eastern Trans	Reported by:	Ken Lewis
Type of	Hawk	Cause of Fatality	Electrocution
LineName	Control-Silverpeak A 55kv	Voltage:	55kv
Location	1 mi W of Five Bridges Road	Pole No.	1843430E
Environmental Setting	Sagebrush		
Weather Conditions	clear	Photo?	No
Have there been other incidents? Describe:	second in 1998		
Recommendations:	monitor area for raptor activity. This area has not be a problem in the past.		
Other Comments:	Bird attempted to land or take off. Made contact with middle phase causing relay.		

Date	3/8/98	Time:		Duration:		Source	Raptor Fatality Fo

District	Eastern GOM Rialto	Reported by:	Lorenzo Ramirez
Type of	Red-tailed Hawk	Cause of Fatality	Electricution
LineName	Chino-Archibald-Pedely 106kv	Voltage:	106kv
Location	North side of Santa River crossing	Pole No.	470109E
Environmental Setting	Riverbank scrub coverage		
Weather Conditions	clear and calm	Photo?	No
Have there been other incidents? Describe:	last contact 1/19/98		
Recommendations:	Rubber post insulators, carry around off the end of arms, extending jumper loop out of contact area.		
Other Comments:	Made contact with middle phase		

Date	7/10/93	Time:		Duration:		Source	Raptor Fatality Fo

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Appendix III

FACILITATING DEVELOPMENT OF MULTIPLE-SPECIES CONSERVATION RESERVES AND HABITAT CONSERVATION PLANS: A SYNTHESIS OF RECOMMENDATIONS

FACILITATING DEVELOPMENT OF MULTIPLE-SPECIES CONSERVATION RESERVES AND HABITAT CONSERVATION PLANS: A SYNTHESIS OF RECOMMENDATIONS

MEETING SUMMARY POINTS

The purpose of this paper is to briefly outline the process that workshop participants undertook to first identify, and then resolve, major issues hindering the development and implementation of MS-HCPs. In addition, a brief outline of the specific papers that form the bulk of this supplement is provided.

Expectations and Issues

Workshop participants began by listing key issues to be discussed that were hindering successful completion and implementation of MS-HCPs. Throughout the workshop, the group returned to this initial list to (1) determine if these issues were being covered, and (2) to supplement the list as new issues and problems arose. The initial list was not meant to provide a group assessment, but rather, to simple get issues on the table for discussion; these were:

1. Avoidance of a "cookbook" approach to designing HCPs.
2. The importance of developing standard applications of science to the HCP process
3. The relationship between the HCP enabling legislation (i.e., Section 10 of the Endangered Species Act) and the application of science to the HCP process
4. Incorporation of a rigorous peer review process
5. Applications of ecological and population models to HCP development
6. The perspective of management and regulatory agencies into practical HCP development
7. In general, what steps can be taken to improve the HCP process
8. Methods to improve communication among all parties (stakeholders) involved in developing and approving a permit application, including pubic education and comment
9. The quality of the data that should go into developing an HCP, and how to deal with scientific uncertainty
10. What role do mitigation banks have in HCPs
11. Reserve design (including buffer areas), and the related issue of reserve management
12. The use of monetary incentives for improving HCP design and implementation, and in changing existing HCPs in light of new information

Additional Issues

At the end of the first day of the workshop, participants reviewed their initial issues list (see above), and added the following items for further consideration:

1. Should plans be written from the "bottom-up", whereby science drives the planning process; or from the "top-down", whereby major planning issues are first identified

and then science is brought to bear on key issues. In short, when should science enter the process
2. The role of HCPs as repositories for plants and animals that are being eliminated elsewhere through development
3. Public availability of data for use in development of HCPs
4. What is the likely direction for the use of HCPs into the future
5. How can an approved HCP be improved in light of new information; this topic relates to the issue of adaptive management
6. How can new research initiatives (to improve data quantity and quality) be incorporated into an HCP
7. How is "success" of an HCP measured
8. What is the proper role for HCPs to contribute to (Endangered Species) Recovery Plans
9. The problems associated with the lack of available expertise in developing and then reviewing a plan

<u>Conclusions and Guides for Improving HCPs</u>
At the conclusion of the workshop, participants again reviewed their initial and modified list of issues and expectations (see above), and developed the following set of conclusions and recommendations for improving the HCP process.

1. Revise the HCP handbook.—There was general consensus that the current Handbook was too vague and did not provide adequate guidance on most aspects of HCP development. Sections that needed addition or strengthening included:
   a. How to access and incorporate stakeholder input throughout the planning process
   b. Guidance on how U.S. Fish and Wildlife Service (FWS) personnel could be incorporated into all phases of a plan's development
   c. A clear discussion of adaptive management that cross-walked with current scientific literature on the topic
   d. Guidance on linking plan goals to measures of project success, and how success could be determined through post-implementation monitoring (e.g., study design, appropriate statistical analyses)

The Department of the Interior issued a draft addendum to the HCP Handbook in March 1999 (Federal Register, Volume 64, No. 45) that addressed many of these issues, including establishing clear biological goals and objectives, clarifying the role of adaptive management, designing monitoring programs, and enhancing public participation in the HCP process. This addendum, if strictly followed, adds a much needed level of rigor to the HCP process.

2. A statement from FWS needed to be made regarding the use of population viability analyses (PVA) in plan development and evaluation; what are the data requirements and allowable uses of a PVA? The goals for population modeling needed to be clearly stated.
3. The scientific uncertainty associated with each major data set and decision in a plan needs to be clearly elucidated. This will allow plan proponents to have a better

understanding of what they are proposing, and will allow all stakeholders to gain a better sense of the strengths and weaknesses of the data that went into a plan alternative

4. The standards for acceptable data (in plan development) need to be clarified. A general consensus emerged that "best available" data is too vague, because the best might not be reliable. Thus, the quality of each data set used in plan development must be clearly discussed
5. Standards should be established for how all material used to build an HCP are referenced. Although there was no consensus on how this should be reported to the public, it was agreed that a clear link between each decision within an HCP and the source of material used to arrive at the decision be established. For example, a decision could be based on anything from expert opinion to peer reviewed literature. Identifying this link is essential for informed review of any plan.
6. It was recommended that independent peer review be incorporated into each major stage of the planning process. This process would identify weaknesses in all data sets and preliminary decisions, and help reduce overall approval time of a plan.
7. It was agreed that project management, including a detailed front-end scoping of a plan, be initiated by the FWS. This would more clearly identify major issues that needed to be addressed early in the process
8. The issue of "species based" versus "ecosystem based" plans needs clarification. Although there was consensus that plans should consider multiple species, it is important that all parties to a plan realize that "umbrella" or "indicator" species approaches seldom adequately protect all species covered under an HCP. This is because each species has unique habitat and niche requirements. Thus, an "ecosystem" approach is best understood as a "multiple species" approach.
9. Greater emphasis should be made at incorporating all stakeholders, including agencies, at all stages of the planning process. Greater attempts should be made to gather as much public input as possible throughout the process. The HCP addendum provides additional guidance in this area.
10. It was agreed that the FWS has not been adequately funded by Congress to manage the HCP process. Thus, new funding mechanisms need to be developed to increase the number or personnel available. A recommended option was for permit applicants to financially support FWS and other agencies for personnel for the duration of a planning process. For example, there was agreement that an agency person should be assigned to assist with project management, and that the permit applicant financially support an agreed-upon portion of the person's time. This would have the added benefit of increasing stakeholder involvement.
11. It was agreed that people possessing a wider range of skills be incorporated into the planning process than is now generally the case. Specific skills needed include expertise in:
    a. local land use planning issues and regulations
    b. project management
    c. hydrology
    d. conservation biology, wildlife biology, and ecology
    e. knowledge of best management practices—BMPs

f. engineering
g. adaptive management
h. study design (including impact assessment) and monitoring
i. preserve management

12. The specific goals of each plan over time, and specific criterion for measuring success of the plan, must be stated
13. There appears to be general confusion on the role that an HCP can play in recovery of a species. The law specifically forbids an HCP to substitute for a Recovery Plan. However, HCPs are expected to contribute to species recovery. The FWS needs to better clarify the role of an HCP in recovering a species, especially given that HCPs usually permit take of covered species.
14. It was agreed that all stakeholders needed a basic understanding of project financing. This would help people understand what a permit applicant could and could not accomplish with regard to mitigation and other plan requirements.
15. It was agreed that there was often inadequate time available to fully design and implement an adaptive management approach into the HCP plan. As such, with the caveat that adaptive management should be incorporated during plan development, it was suggested that established best management practices (BMPs) could be used to establish HCP preserves. Then, as data are gathered, a more formal adaptive management strategy could be implemented. Of course, the requirement for incorporation of such an adaptive management plan would need to be explicitly stated and designed into permit approval. However, BMPs allow evaluation of a proposed and developing preserve and describe the initial actions recommended for improvement of the habitat of specific covered species. There are many such models available (e.g., state forest practice rules), and efforts could be expended on synthesizing available data and expert opinion into developing BMPs for covered species. In addition, BMPs can be gathered that address principles of reserve design and management.
16. The admitted evolving nature of HCP program administration by the FWS causes challenge of interpretation of rules by permit applicants. The FWS needs to expend the resources necessary to establish firm guidance for it's various offices and personnel throughout the U.S.
17. There needs to be clear guidance on what constitutes acceptable mitigation from the standpoint of endangered species policy. A helpful addition to HCP guidance by the FWS would be examples of recommended strategies for mitigating project impacts. Guidance involving major concepts of reserve design, the use of buffer areas and corridors, monitoring standards, and so forth should be established. All guidance should be directly keyed to the relevant scientific literature.
18. There was consensus that each HCP should contribute to overall understanding of ecological processes driving the HCP concept. That is, projects should be planned so that successes and failures in strategy and implementation can be documented so that future projects can benefit. For example, if corridors are implemented as mitigation for fragmenting a preserve, then research should be incorporated into the monitoring phase of the project so the success of the corridor can be determined. This process should also instill confidence in all stakeholders regarding the seriousness of the FWS

and permit applicant in devising a plan that promotes species survival. Such research-monitoring activities will be most successful if packaged with a workable adaptive management strategy that includes a funding vehicle for allowing future changes in the HCP.

19. Each area and the species within it have their own unique distributions; HCPs should not become museum pieces of tiny fragments, rather they should cohesively act as protection measures throughout a species distribution, complementing but not replacing Recovery Plans.
20. Lands to be developed ("taken") could be viewed as research tools, so that certain ecological experiments could be performed prior to habitat destruction. Additionally, consideration should be given to removing (transplanting) selected animals and plants if there is concern over loss of genetic diversity. The HCP addendum briefly discusses (in the form of any example) the use of translocations under an adaptive management scenario.

WORKSHOP PRESENTATIONS

The remainder of this supplement provides most of the formal presentations made during the workshop. Formal presentations were given to provide background information, and serve as a catalyst for discussion. The workshop papers were divided into two major sections. The first deals primarily with the legal foundation of the HCP process, perspectives from the standpoint of an environmental group and local and county governments, and weaknesses between the HCP Handbook and implementation of actual HCPs. The second section covers many of the scientific foundations of planning for multiple species preserves, including fundamental concepts of conservation biology, modeling the extinction process, landscape planning and animal habitat, and the lack of knowledge regarding the status of arthropods. The papers that follow cover:

Regulatory Issues and HCP Planning

The legal foundation of HCPs and the ESA.—David E. Moser outlines that often substantial confusion that exists among stakeholders regarding what is and is not mandated in Section 10 of the Endangered Species Act (ESA). Unfortunately, this confusion leads to misapplication of the law, and hinders the successful implementation of a plan. Moser briefly reviews the federal ESA, including what constitutes "take"; and then details the legal requirements that pertain to developing an HCP.

Perspectives from the National Audubon Society (NAS.—John McCaull first reviews the often-conflicting views held by environmental groups regarding the HCP process. He then details the position NAS has taken on HCPs, including specific recommendations that are being made to enhance stakeholder acceptance of plans that allow post-approval changes in light of new information.

Perspectives from local governments.—Brian Loew reviews the goals that local governments and developers have in entering an HCP process. Of primary concern is maximizing certainty in future planning efforts. HCPs are usually viewed as a negotiated document that draws compromises between the desire to grow the human infrastructure and the desire to maintain species diversity and open space.

Perspectives from county governments.—Robert C. Copper reviews how the HCP process has evolved in San Diego County, California. He identifies the multifaceted steps needed to establish a large (~70,000 ha) preserve in a rapidly developing planning region of over 224,000 ha. He makes suggestions regarding improving the permitting process.

Relating the HCP Handbook to the ESA and HCP development.—K. Shawn Smallwood draws comparisons between what the HCP Handbook provides as guidance to permit applicants, what the ESA mandates, and how several actual HCPs were developed. His comparison identifies major inconsistencies, and he makes recommendations for improving the guidance provided to permit applicants (see also the workshop summary, above).

<u>Conservation Biology and HCP Development</u>

Application of conservation biology tenets to HCP development.—Thomas A. Scott lays the foundation for the technical papers that follow by outlining the application of principles of conservation biology to HCP development and preserve design. He also makes the point that GIS-based maps are concepts—simplifications of reality—that have substantial limitations when applied to preserve design.

Extinction analysis and HCP development.—Patrick Foley presents a modeling approach to predicting the likelihood of survival of a species within a preserve. He outlines an approach (Bayesian) that, among other features, allows stakeholders to agree on sets of values to work from, and allows modification of models as new information becomes available.

Linking population models with the landscape.—H. Resit Akcakaya presents a procedure for linking population models with GIS-based mapping of habitat to make predictions about species distributions following plan implementation. This approach may allow users to view the landscape under various planning scenarios.

Ecological restoration and the HCP process.—Peter A. Bowler presents approaches to restoring plant and animal communities as part of an HCP. He uses data from California coastal sage scrub to show how transplanting "whole" communities can enhance restoration and mitigation.

The great unknown: endangered arthropods.—Richard A. Redak identifies how the lack of knowledge regarding arthropod taxonomy is hindering identification of priority areas for mitigation and restoration. He estimates that only about half of the arthropod species have been identified. Thus, until greater knowledge on arthropod taxonomy is gathered, we risk losing numerous species because of insufficient knowledge. Many of the species likely to be lost function in plant pollination and in controlling of other arthropods (e.g., those causing crop damage and disease).

CONCLUDING COMMENTS

This supplement presents recommendations for improving the HCP process, from enhancing the ability of regulators to respond to the needs of permit applicants, to enhancing our understanding of the conservation principles underlying sound preserve design. We view this contribution as a stimulus to enact specific recommendations, and as a springboard for further discussion and improvement of planning efforts.

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Appendix IV

Population Dynamics, Dispersal and Demography of California Gnatcatchers in Orange Co., California (1998 Progress Report)

Reporting research results from coastal Orange County (1995-1998)

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INTRODUCTION

A critical aspect of the State of California's Natural Community Conservation Planning (NCCP) program is the central role that science is intended to play in the formulation of land-use planning decisions and policies (California Department of Fish and Game and California Resources Agency 1993). By applying principles of modern conservation biology to data on the distribution, ecology, and population dynamics of selected plant and animal species, an important objective of NCCP is to design regional reserves that will ensure the long-term viability of rare and declining habitat types (O'Connell and Johnson 1997). Such a "proactive" conservation approach, if successful, may potentially halt the decline of sensitive species dependent on the habitats being considered, and thereby reduce the need to protect biodiversity through the cumbersome regulatory framework afforded by endangered species laws (Atwood and Noss 1994). Conversely, NCCP may also identify areas that are scientifically determined to be less important from a biological standpoint, and where economic development may consequently proceed without fear of triggering further additions to federal or state endangered species lists.

The pilot project of the NCCP program has focused on a plant community known as coastal sage scrub (Reid and Murphy 1995), which is patchily distributed in southern California in the coastal lowlands west of the Transverse and Peninsular ranges. Historically, coastal sage scrub was a dominant feature of the southern California landscape, where it occurred widely in a natural matrix that also included grassland, chaparral, and oak woodland communities. Today, as a result of urban and agricultural impacts, 70-90% of the historic acreage of coastal sage scrub is estimated to have been lost (Westman 1981; O'Leary 1990), and those tracts of scrub that remain in the region generally occur as "islands" surrounded by ever-increasing "seas" of urban development. Habitat loss and fragmentation has caused nearly 100 species and subspecies of plants and animals belonging to the coastal sage scrub community to decline to the point that federal and state wildlife agencies have formally designated them as endangered or threatened, or identified them as potential candidates for such listing (Atwood 1993).

The NCCP coastal sage scrub Scientific Review Panel selected three "target species" to use as the focus of conservation planning efforts for this habitat type: California gnatcatcher (*Polioptila californica*), cactus wren (*Campylorhynchus brunneicapillus*), and orange-throated whiptail (*Cnemidophorus hyperythrus*) (California Department of Fish and Game and California Resources Agency 1993). Although different or additional species are, in practice, being used as surrogates for coastal sage scrub conservation planning in various areas of southern California, virtually all NCCP efforts that have been initiated to date have included maintenance of viable populations of California gnatcatchers as a principal objective. Sound ecological and behavioral information about this species will thus play a critical role in the preparation of NCCP plans and contribute to evaluation of the program's success.

Research on gnatcatcher population dynamics was initiated in coastal Orange County in 1995 under auspices of The Superpark Project (Ed Almanza & Associates), building on population survey and banding efforts that began in 1991. Complementary work on gnatcatcher biology was conducted by Manomet Center for Conservation Sciences on the Palos Verdes Peninsula, Los Angeles County, from 1993 - 1997. The primary objectives of this study have been largely defined by the research needs identified in the NCCP coastal sage scrub conservation guidelines prepared by the California Department of Fish and Game and California Resources Agency (1993). These objectives include: (1) develop GIS data layers delineating the extent of coastal sage scrub vegetation and the distribution of California gnatcatchers; (2) determine the extent and causes of annual variation in gnatcatcher reproductive success, survivorship, and territory size; and (3) collect data on factors affecting the dispersal behavior of gnatcatchers. More recently this general agenda was reaffirmed by the "NCCP Core Group", a diverse group of researchers and land managers who concluded, in part, that "Individual species, particularly listed species and/or certain species deemed to be targets for natural community conservation efforts, continue to be focal issues for conservation programs. In order to manage for the long-term conservation of these species, managers need to understand the population demographics and ecological relationships of these species with their environment. This understanding applies to a given species and its ecological relationships at the landscape level, the intrinsic demographic variability of the species, and the genetic diversity among and within populations of the species" (Science & Policy Associates 1997).

Due to the continuing process of data entry and editing, the results presented here supersede those described in any previous progress reports (Atwood et al. 1998; Bontrager et al. 1995b; Bontrager et al. 1997; MacMillen et al. 1991; Woehler 1994, 1995). Any use of results presented here in manuscripts being submitted for formal publication must first be approved in writing by Dr. Peter Bowler (University of California, Irvine) or Dr. Jonathan Atwood (Antioch New England Graduate School).

METHODS

Study areas. -- This report includes information collected in coastal Orange Co., California. Six principal study sites were delineated in coastal Orange County by arbitrarily defining discrete patches of coastal sage scrub as those areas that are isolated from one another by distances of at least 1 km (Atwood et al. 1998b). These sites are referred to as: (1) Turtle Rock (including areas referred to previously reports as Ridgeline, Sand Canyon Wash, Sand Canyon Reservoir, Turtle Rock Fragments A-D, Turtle Rock Ridgeline, and Turtle Rock Reservoir; Bontrager et al. (1995b; Bontrager et al. (1997); (2) Newport Bay; (3) UCI Ecological Preserve; (4) Crystal Cove Bluff (northern portion of California State Park west of Pacific Coast Highway); (5) North Laguna Laurel; and (6) Sycamore Hills. Additional descriptions of dominant natural vegetation types, using habitat classifications proposed by Jones and Stokes Assoc. (1993), are provided in Atwood et al. (1998).

Population surveys. -- All major areas of natural habitat located in the six principal study sites were surveyed for breeding California gnatcatchers during February – June of each year of the study (1995 – 1998) by the field research team (DRB, RH, DK, and MM). Surveys were generally conducted before 11:00 h and after 16:00 h, under weather conditions deemed acceptable in terms of wind and temperature. Tape recordings of gnatcatcher vocalizations were used to elicit responses. In areas where closely adjacent territories of unbanded birds posed potential confusion over the number of pairs actually present, teams of biologists would revisit the site in order to obtain simultaneous observations of all birds in question. Population estimates were based on observations of uniquely banded birds, the locations of simultaneously active nests, or simultaneous observations of unbanded birds. Survey intensity greatly exceeded the minimum effort required by U.S. Fish and Wildlife Service protocols (USFWS 1997).

Breeding biology and reproductive success. -- A central aspect of work in coastal Orange County has been the annual identification of "focal" pairs, defined as pairs which were consistently observed throughout an entire breeding season and for which accurate counts were obtained of the total number of fledglings produced. Territories of focal pairs were visited from 1 - 3 days per week, beginning in early March and continuing into July or August. Nests were located through direct observation of nest building, nest exchanges, or feeding of nestlings. All successful nesting attempts of each of these focal pairs were detected. The number of juveniles fledged from each successful nest was based on counts, usually of banded birds, that were made 1 - 5 days after fledging.

We defined "focal pairs" as equivalent to "focal females". That is, a female which was observed with multiple mates during a single nesting season would still be considered to represent a single "focal pair" from the standpoint of calculating reproductive success. Conversely, a male which was mated to multiple females during a single year might belong to several "focal pairs", even if all pairings of this male occurred on precisely the same territory. Under this approach we assume that paired females which vanished during the course of the breeding season died, as opposed to divorcing and moving to a new locality where we failed to detect them. For example, a female for whom all reproductive efforts were thoroughly documented prior to her disappearance in mid–May might still be considered a "focal" bird, even though we recognize that the female may have divorced her first mate and moved to a new area where she continued to nest for the duration of that season without our detection. Although this may be a somewhat tenuous assumption, it is nonetheless consistent with data from the Palos Verdes Peninsula where individuals that have disappeared mid-season have, in almost all cases, never been relocated elsewhere within the study area (Atwood et al., unpubl. data). Similarly, we have assumed here that an unbanded female associated with a particular territory was not replaced by another unbanded (and therefore indistinguishable from the first) female during the course of the season. Only a small fraction of our samples of "focal pairs" involved banded females that disappeared during the course of a breeding season.

To minimize potential impacts associated with monitoring activities, visits by biologists to gnatcatcher nests were generally limited to 2 – 3 dates from the beginning of nest building to fledging. The initial visit was made when feeding of nestlings was first observed in order to estimate the age of juveniles that were present and thereby schedule a follow-up banding visit. This second visit was then made at approximately 8 days of age; handling nestling gnatcatchers before this age was deemed impractical due to the birds' small size. We made no effort to expand the presently available data on clutch size, as our primary goal was to determine the total number of fledglings produced annually by each pair. Nests were not visited when western scrub-jays (*Aphelocoma californica*), loggerhead shrikes (*Lanius ludovicianus*), or brown-headed cowbirds (*Molothrus ater*) were seen nearby.

We used Japanese mist nets to capture adult and fledgling gnatcatchers for banding; birds were usually attracted to the vicinity of the nets by playback of recorded vocalizations. Two colored plastic leg bands were used in conjunction with the numbered USFWS. Banding efforts as reported to the USFWS Bird-Banding Laboratory are detailed in Appendix A, and summarized in Table 1.

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TABLE 1. SUMMARY OF CALIFORNIA GNATCATCHER BANDING TOTALS (BY AGE) IN COASTAL ORANGE COUNTY. AGE CODES REFER TO AGE AT TIME OF INITIAL CAPTURE. L = LOCAL (JUVENILE BIRD INCAPABLE OF SUSTAINED FLIGHT; HY = HATCHED IN SAME CALENDAR YEAR AS BANDED; AHY = BANDED AT ONE OR MORE CALENDAR YEARS AFTER HATCHING; U = UNKNOWN).

	AGE AT TIME OF BANDING				
	L	HY	AHY	U	TOTALS
1991	0	0	0	1	1
1992	0	1	4	0	5
1993	45	3	12	40	100
1994	76	8	38	22	144
1995	163	8	15	8	194
1996	133	35	45	0	213
1997	204	100	64	5	373
1998	181	47	13	0	241
TOTALS	802	202	191	76	1271

Dispersal behavior. -- Direct-line distances were used as the basis for evaluating the dispersal behavior of juvenile California gnatcatchers. Banding and resighting locations were described within a 1000 ft X 1000 ft grid pattern superimposed over each study area; distances were calculated between the centers of each of these grid cells using Arc/INFO's POINTDISTANCE function, and rounded to the nearest 0.1 km. To reduce the likelihood of including observations of birds that had not yet begun or completed dispersal away from their natal territories, we excluded all resightings obtained < 100 days after the initial banding date. In instances where a dispersing individual was observed on multiple dates after this restriction was imposed, mean distances between natal site and subsequent observation points were calculated.

Survivorship. -- Survivorship estimates for adults and juveniles were calculated between the nesting seasons of 1993 – 1994, from 1994 – 1995, from 1995 – 1996, from 1996 – 1997, and from 1997 - 1998. Birds were included as being alive in a given year even if they were not actually recorded until following years; that is, we "filled" years of observation gaps based on subsequent sightings.

RESULTS

Population size and distribution. -- Seventy-two to 96 breeding pairs of California gnatcatchers were found in the coastal Orange County study sites (excluding Crystal Cove Bluff and small areas at North Laguna Laurel, Turtle Rock (Sand Canyon Reservoir), and Sycamore Hills that were not consistently surveyed throughout the study period) during surveys conducted from 1993 - 1998. Seventy-two pairs were located in 1998. Apart from a one-year increase that occurred during 1994, likely as a result of immigration of birds displaced by the Laguna fire of October 1993 (Atwood et al., 1999, populations in our study areas have been essentially stable from 1993 – 1998 (Fig. 1).

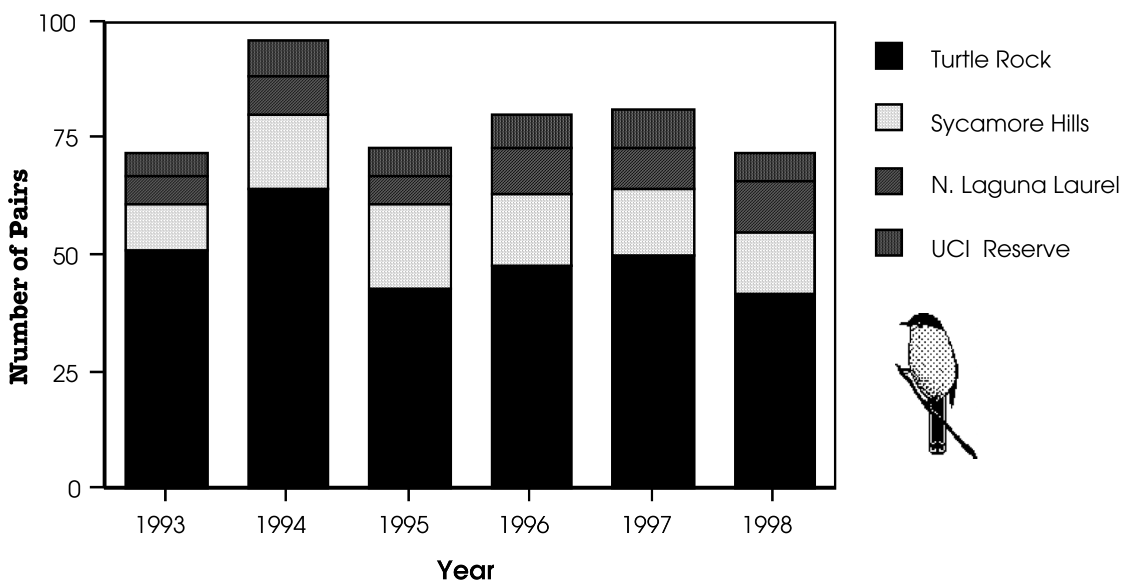

FIGURE 1. ANNUAL FLUCTUATION IN POPULATION SIZE OF CALIFORNIA GNATCATCHERS IN COASTAL ORANGE COUNTY STUDY PLOTS (1993 – 1998).

Reproductive success. -- Table 2 summarizes data on gnatcatcher reproductive success in coastal Orange County from 1995 – 1998. The were no significant annual differences in gnatcatcher reproductive success among these years (Kruskal-Wallis test; H corrected for ties = 2.26, P = 0.52; Fig. 2).

TABLE 2. REPRODUCTIVE SUCCESS (NUMBER OF FLEDGLINGS PRODUCED PER PAIR PER YEAR) OF CALIFORNIA GNATCATCHERS IN COASTAL ORANGE COUNTY.

YEAR	X (# fledglings)	s.d.	n (pairs)	Range (# fledglings/pair)
1995	2.66	2.42	38	0 - 8
1996	2.29	2.14	38	0 - 8
1997	2.59	2.45	76	0 - 8
1998	3.02	2.55	57	0 - 8

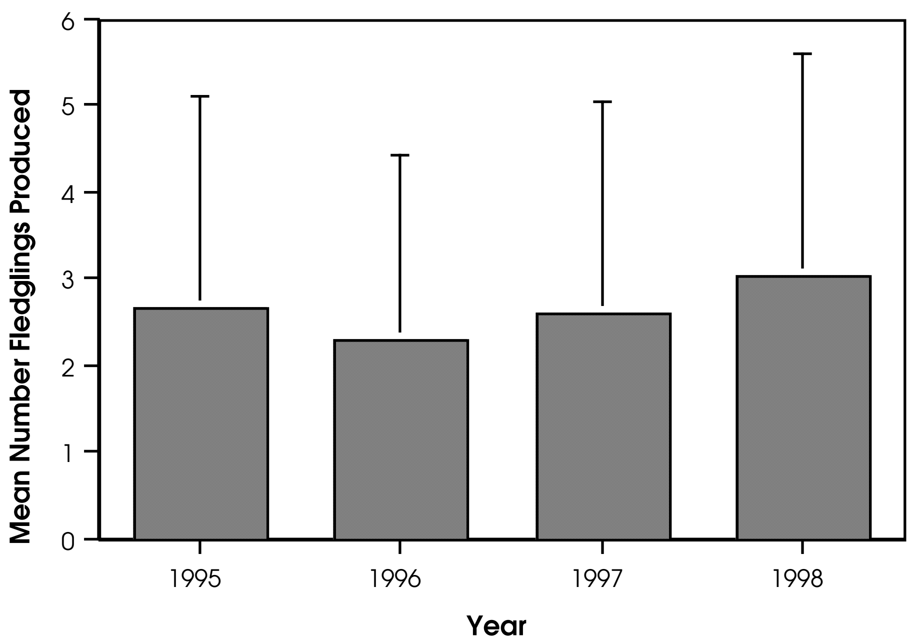

FIGURE 2. ANNUAL VARIATION IN REPRODUCTIVE SUCCESS OF CALIFORNIA GNATCATCHERS IN COASTAL ORANGE COUNTY (1995 – 1998). ERROR BARS REPRESENT 1 STANDARD DEVIATION.

We also compared reproductive success between study sites dominated by *Artemisia californica* (Turtle Rock, UCI Ecological Preserve, Newport Bay, Crystal Cove Bluff) and sites where the coastal sage scrub community had a stronger chaparral component (including frequent dominance by *Salvia mellifera*) (Sycamore Hills and North Laguna Laurel). During each year of the study there were no significant differences in the number of fledglings produced between these two categories of sites (Mann-Whitney U-test, $P > 0.05$; Table 3). We have not yet fully analyzed other aspects of reproductive behavior, but note that in 1998 there was a significant difference between *Artemisia*-dominated and *Salvia*-dominated sites in the frequency of occurrence of pairs with 0, 1, and 2 successful nesting attempts (Likelihood Ratio chi-square = 7.640, $P = 0.02$), with the relative rarity of 2 successful nesting attempts in *Salvia*-dominated sites especially deviating from expected (Fig. 3).

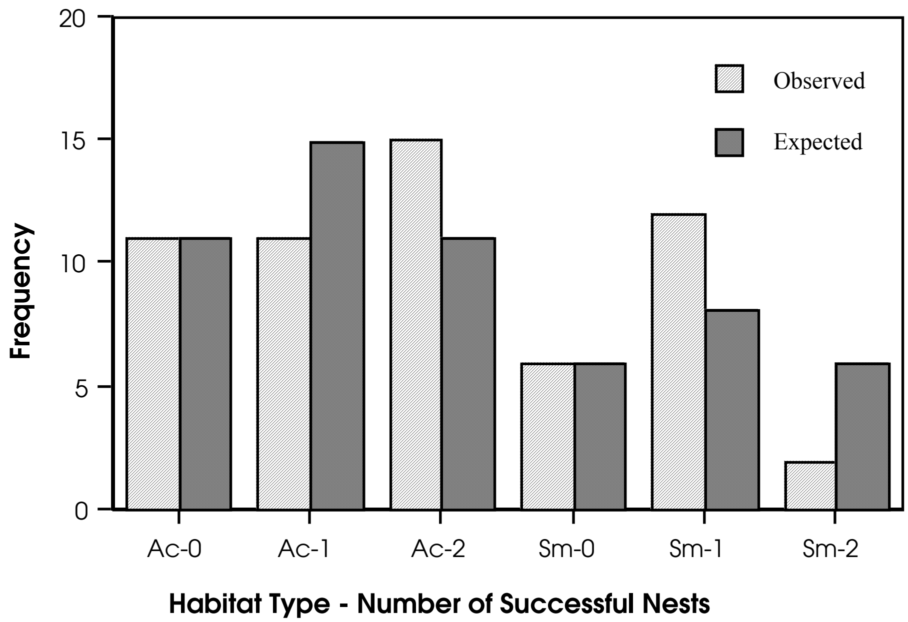

FIGURE 3. OBSERVED AND EXPECTED FREQUENCIES OF PAIRS WITH 0, 1, AND 2 SUCCESSFUL NESTING ATTEMPTS IN HABITAT DOMINATED BY ARTEMISIA CALIFORNICA (Ac) AND SALVIA MELLIFERA (Sm).

TABLE 3. REPRODUCTIVE SUCCESS (NUMBER OF FLEDGLINGS PRODUCED PER PAIR PER YEAR) OF CALIFORNIA GNATCATCHERS IN HABITAT DOMINATED BY ARTEMISIA CALIFORNICA AND SALVIA MELLIFERA(1995 – 1998).

Dominant CSS species	X (# fledglings)	s.d.	n (# pairs)
1995			
Artemisia californica [a]	2.48	2.48	28
Salvia mellifera [b]	1.90	1.90	10
1996			
Artemisia californica [a]	2.64	2.64	28
Salvia mellifera [b]	1.30	1.30	10
1997			
Artemisia californica [a]	2.38	2.35	58
Salvia mellifera [c]	2.78	2.80	18
1998			
Artemisia californica [a]	3.19	2.69	37
Salvia mellifera [c]	2.70	2.32	20

[a] Study sites = Turtle Rock, UCI Ecological Preserve, Newport Bay, Crystal Cove Bluff.
[b] Study sites = Sycamore Hills.
[c] Study sites = Sycamore Hills, North Laguna Laurel.

Survivorship. -- Table 4 summarizes California gnatcatcher survivorship data for adult and juvenile cohorts known to be alive in 1993, 1994, 1995, 1996, and 1997. Because dispersing juveniles may easily move into areas where they are unlikely to be encountered as part of our research efforts, estimates of juvenile survivorship must be considered minimum values. In particular, because the Palos Verdes Peninsula functions as a closed system in comparison to Orange County study sites, estimates of juvenile survivorship to year 1 are probably more accurate from Palos Verdes than from Orange County (Table 4).

Comparisons of survivorship estimates between Orange County and Palos Verdes failed to detect any significant difference between the two localities for adults of either sex (Mann-Whitney U-test, $P > 0.10$) (Fig. 4). Based on combined data from both study areas, there was no difference in mean survivorship estimates of males ($x = 0.52$, s.d. = 0.173, $n = 9$) vs. females ($x = 0.62$, s.d. = 0.159, $n = 9$).

TABLE 4. SURVIVORSHIP OF CALIFORNIA GNATCATCHERS IN COASTAL ORANGE COUNTY (1993 - 1998) AND ON THE PALOS VERDES PENINSULA (1993 - 1997).

Annual Survivorship Estimates

SITE	YR1-YR2	JUV	N	AHY M	N	AHY F	N
OC	93-94	0.063	48	0.556	9	0.857	7
OC	94-95	0.155	84	0.400	50	0.550	40
OC	95-96	0.187	171	0.659	44	0.703	37
OC	96-97	0.113	168	0.695	82	0.610	59
OC	97-98	0.133	309	0.561	98	0.513	80
PV	93-94	0.284	74	0.417	12	0.667	12
PV	94-95	0.195	77	0.147	34	0.289	38
PV	95-96	0.431	51	0.625	16	0.727	22
PV	96-97	0.214	70	0.625	24	0.615	26

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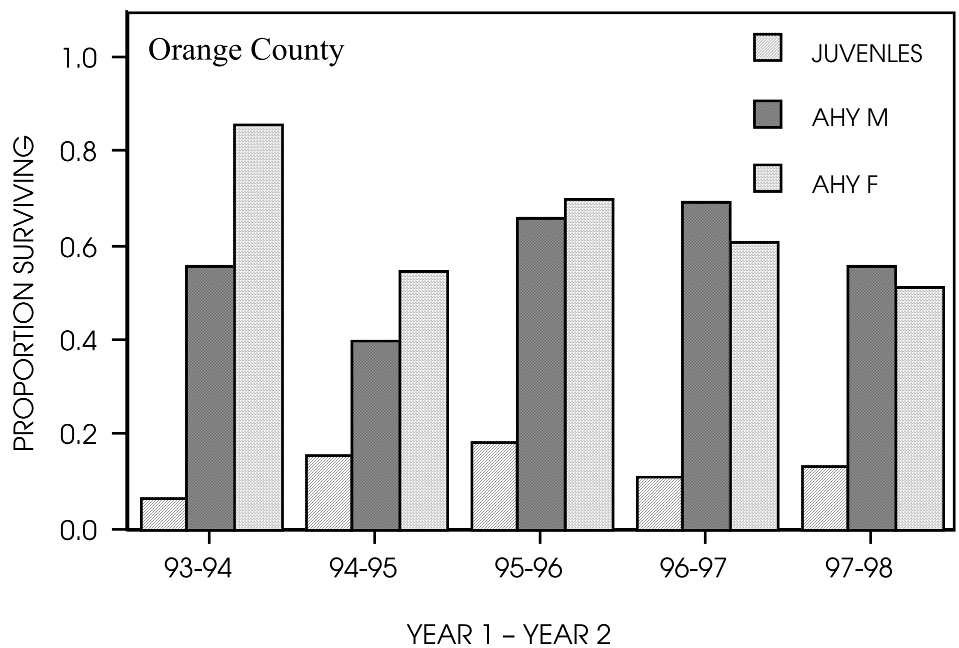

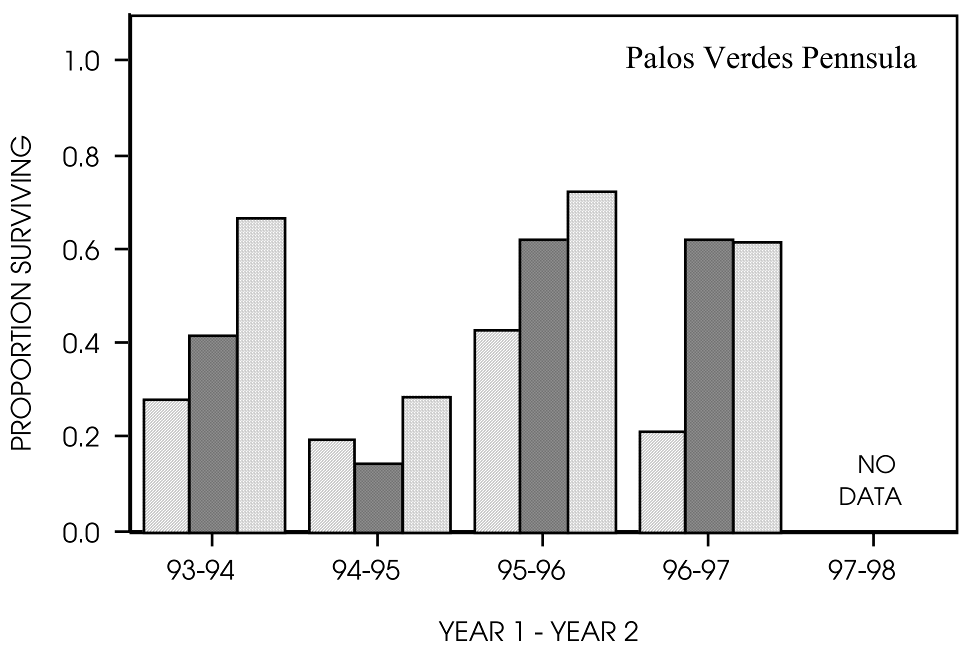

FIGURE 4. ANNUAL VARIATION GNATCATCHER SURVIVORSHIP ESTIMATES FROM ORANGE COUNTY AND THE PALOS VERDES PENINSULA.

Dispersal behavior. -- Gnatcatcher dispersal data were restricted to only those observations obtained 100 days after banding. Although this restriction eliminated some observations of dispersing birds, we felt it was necessary to avoid biasing the results toward short distances, such as would occur if observations of birds that had not yet moved away from their natal territory were included in the analysis.

We found no significant difference between Orange Co. and the Palos Verdes Peninsula in the dispersal distances of juvenile female gnatcatchers (Wilcoxon rank sum test, Z = 1.48, P = 0.14) or of juvenile male gnatcatchers (Wilcoxon rank sum test, Z = -0.78, P = 0.43) (Figs. 5 and 6). Consequently we combined data from the two areas in order to increase sample sizes (Fig. 7). We found no significant difference between the sexes in dispersal distance (males: mean = 2.95 km, s.d. = 2.68, range 0.0 - 10.2 km, n = 92; females: 2.48 m, s.d. = 2.14, range 0 - 10.1 km, n = 104) (Wilcoxon rank sum test, Z = 0.99, P = 0.32).

Annual differences in mean distances dispersed by juvenile gnatcatchers might conceivably reflect year-to-year differences in habitat saturation. For example, in years when regional population levels are high, relatively few areas of suitable and unoccupied habitat are presumably encountered by dispersing juveniles, thus requiring more extensive searches which result in longer average dispersal distances. In years when population levels are low, dispersing juveniles may succeed in discovering suitable, unoccupied habitat relatively near to their natal territories, resulting in lower average dispersal distances. Although there may be other factors involved which we have not yet addressed, this hypothesis appears to be supported by data collected in Orange County from 1994 - 1998. Juveniles fledged in Orange Co. in 1994, when gnatcatcher population levels were regionally elevated (Erickson and Miner 1998, Atwood et al. 1998a,b), had longer dispersal movements than cohorts fledged in 1995, 1996, and 1997 (Fig. 8; Kruskal-Wallis Test, Chi-square = 10.1896, P = 0.02).

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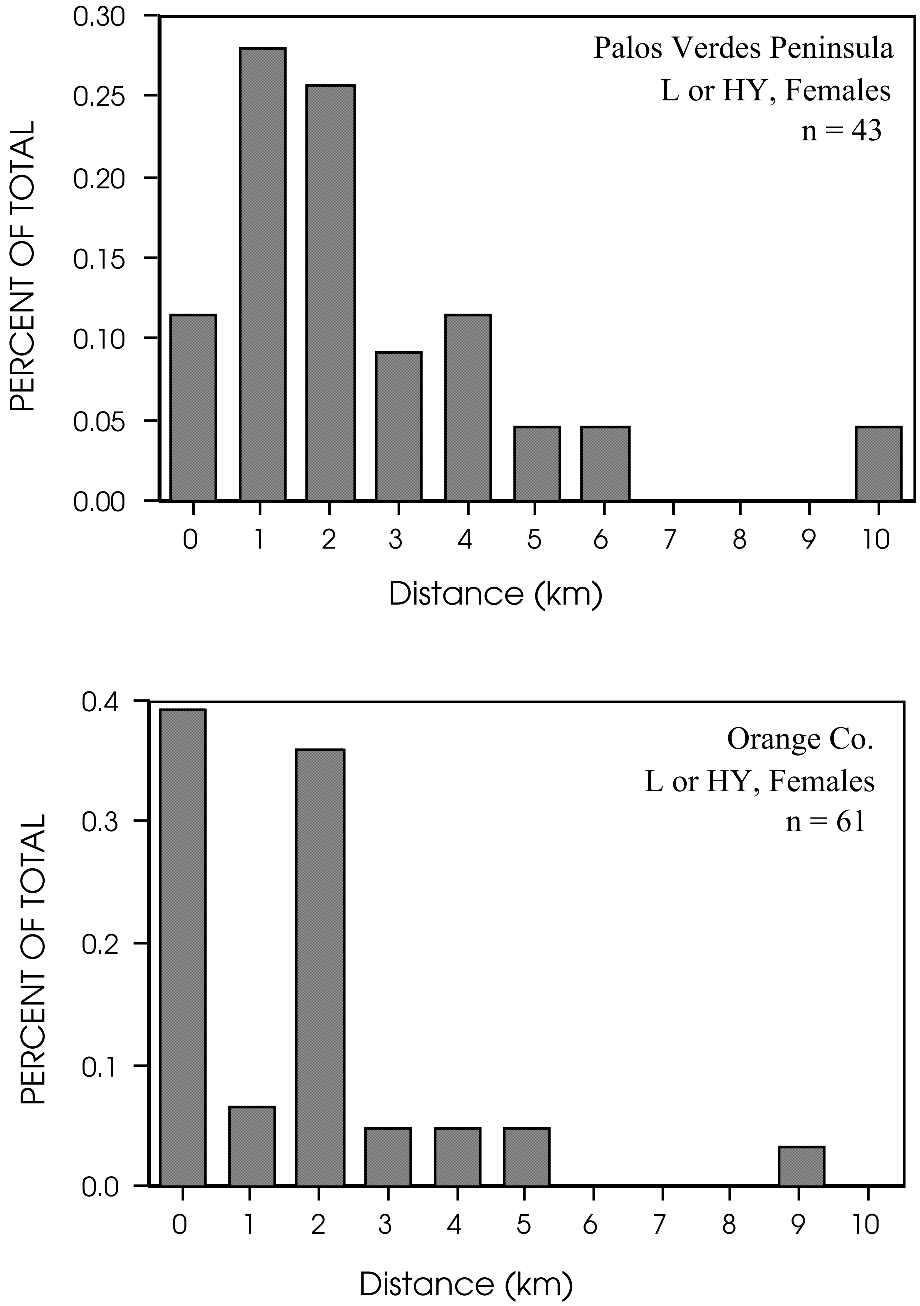

FIGURE 5. COMPARISON OF DISPERSAL MOVEMENTS BY JUVENILE FEMALE GNATCATCHERS IN ORANGE CO. AND ON THE PALOS VERDES PENINSULA.

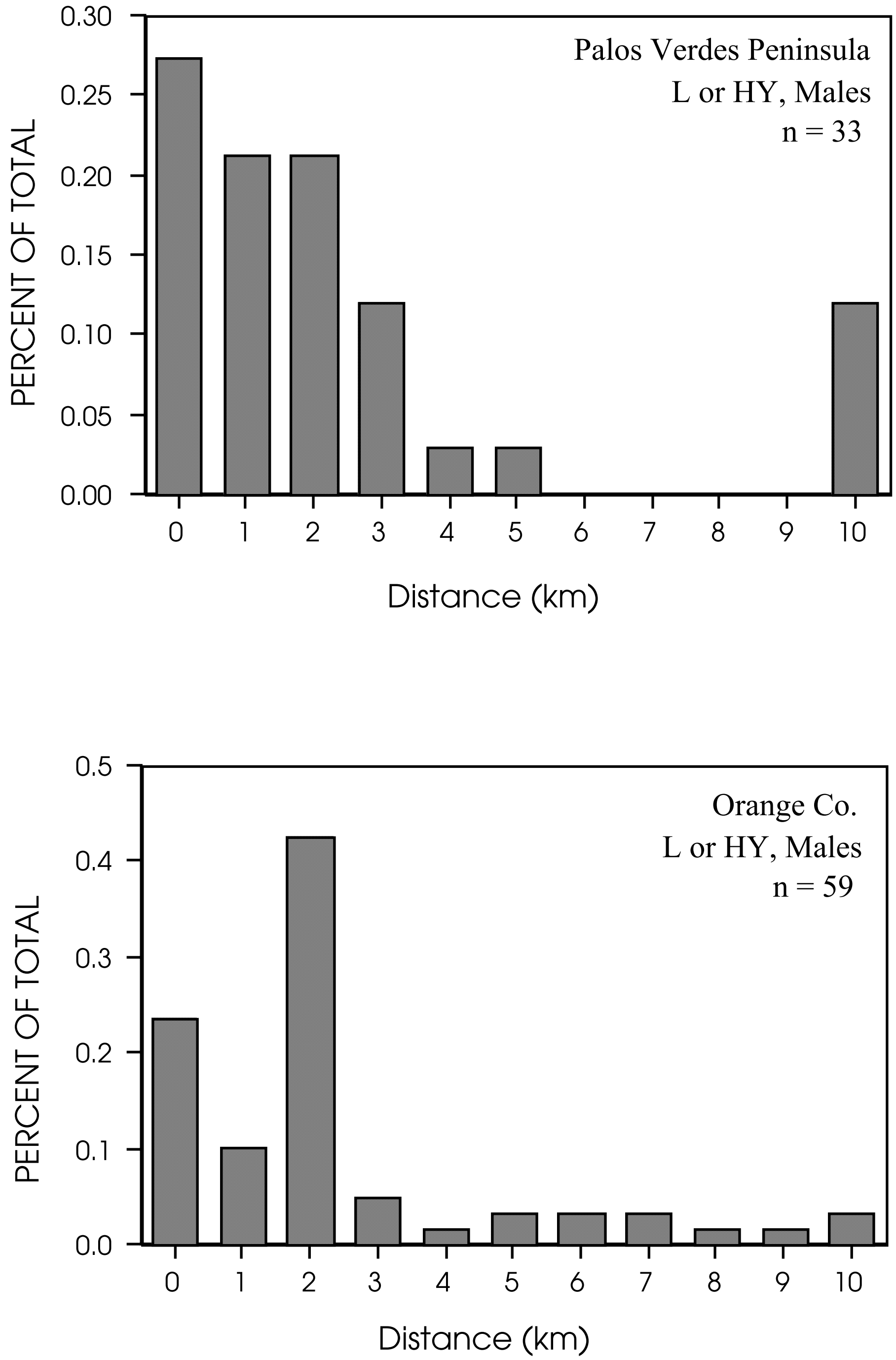

FIGURE 6. COMPARISON OF DISPERSAL MOVEMENTS BY JUVENILE MALE GNATCATCHERS IN ORANGE CO. AND ON THE PALOS VERDES PENINSULA.

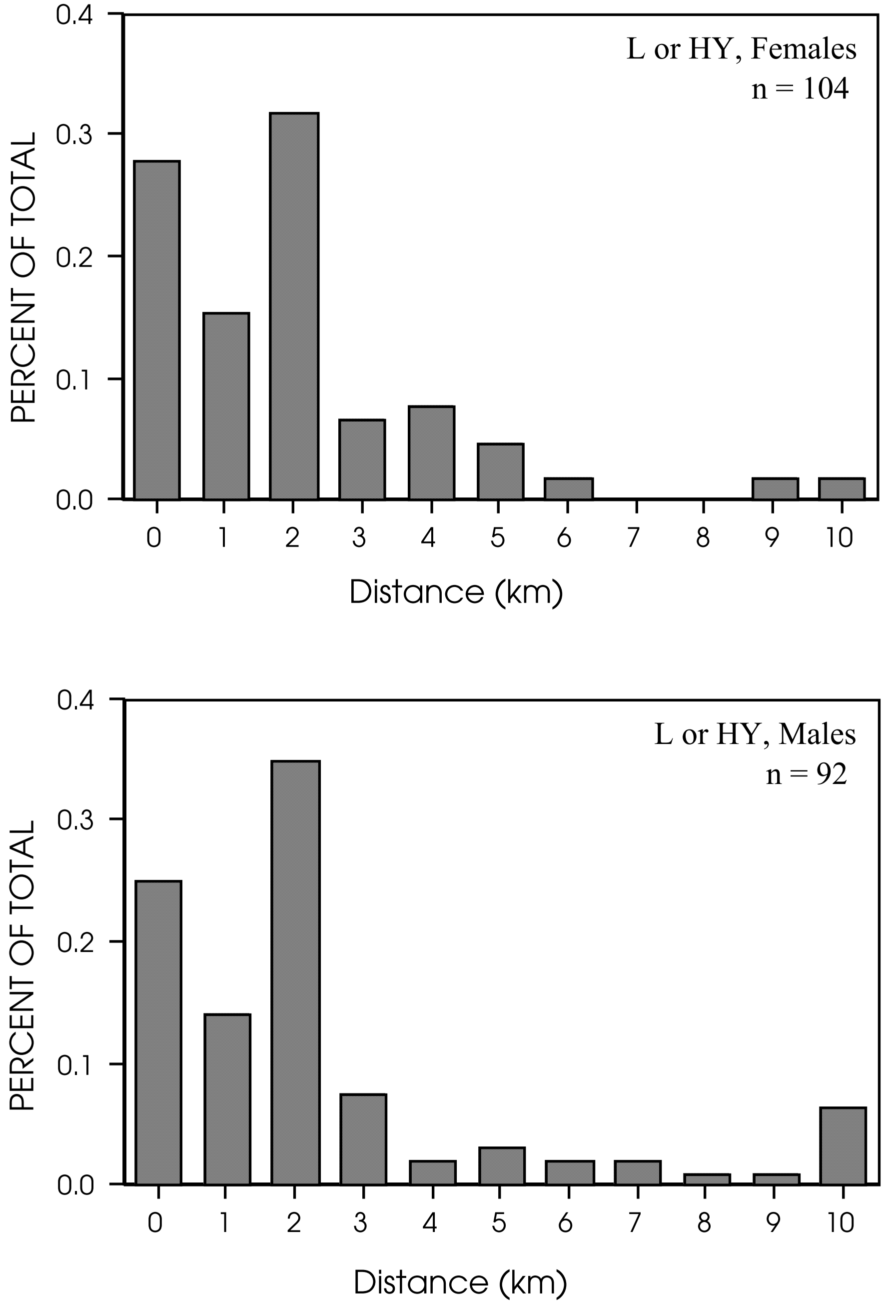

FIGURE 7. COMPARISON OF DISPERSAL MOVEMENTS BY JUVENILE MALE AND FEMALE GNATCATCHERS (BASED ON COMBINED DATA FROM ORANGE CO. AND THE PALOS VERDES PENINSULA).

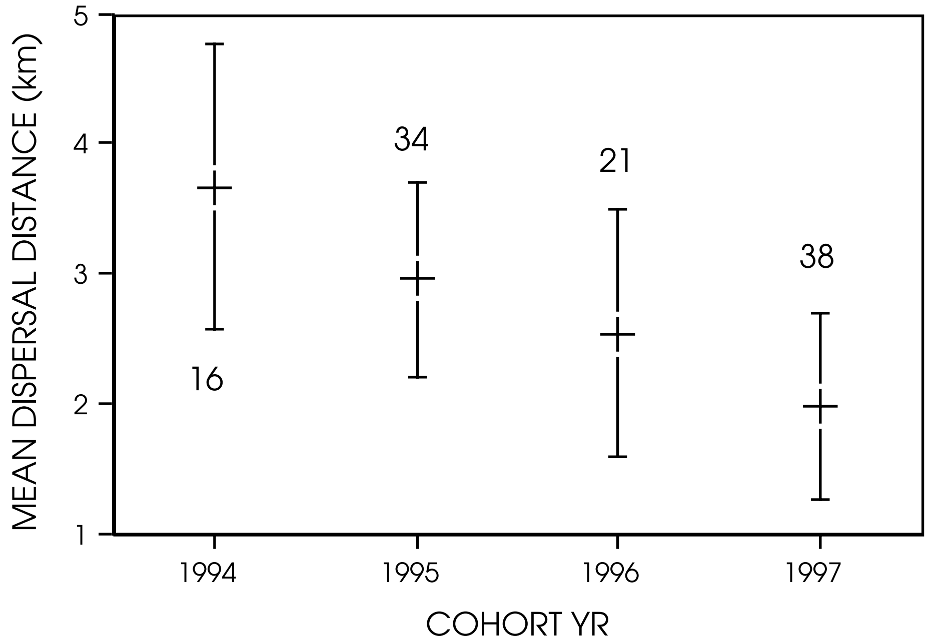

FIGURE 8. MEAN DISTANCES MOVED BY DISPERSING CALIFORNIA GNATCATCHERS FLEDGED IN ORANGE CO. DURING 1994 - 1997. ERROR BARS APPROXIMATE THE 95% CONFIDENCE INTERVAL (2 STANDARD ERRORS). NUMBERS ASSOCIATED WITH EACH YEAR'S BAR REPRESENT SAMPLE SIZES, I.E., NUMBER OF JUVENILES FLEDGED IN THAT YEAR FOR WHICH DISPERSAL OBSERVATIONS WERE OBTAINED AT LEAST 100 DAYS AFTER BANDING.

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DISCUSSION

The results presented here provide basic information about the biology of California gnatcatchers, a songbird species central to southern California's coastal sage scrub habitat conservation planning effort. As such, these data are of major importance in evaluating existing conservation plans, guiding the preparation of new plans, and contribute to the ongoing refinement of habitat and species management objectives. These data go far beyond the typical "monitoring" activities that have too often characterized NCCP research efforts. While such monitoring projects are not without their value, mere counts of pair numbers will simply not provide planners, land managers or regulatory authorities with the tools needed to understand and adaptively respond to specific conservation challenges (Science & Policy Associates 1997). This study (including now-terminated work on the Palos Verdes Peninsula) represents one of the only ongoing efforts aimed at collecting demographic and behavioral data for California gnatcatchers. Because of the major time investment involved in establishing uniquely-banded populations of known-age, known-natal area birds, and the value of such a study population in addressing regional conservation issues, the Palos Verdes / Orange County (coastal) project represents a critical research element contributing to the State of California's NCCP efforts.

It is not our intent in this discussion to comment on all aspects of gnatcatcher biology that our data are relevant to (and, indeed, the results section only touches on certain aspects of the species' behavior while ignoring many topics for which we have extensive data such as predation, phenology of nesting, details of nest placement, annual variation in habitat occupancy, and pair bond fidelity). Instead, we focus here on three specific issues of direct importance to conservation and management efforts, and describe how long-term, detailed demographic studies can potentially clarify conservation issues affecting coastal sage scrub reserves. These specific issues include:

(1) what factors influence patterns of dispersal by California gnatcatchers?
(2) what factors influence year-to-year fluctuations in California gnatcatcher population sizes, and what are the implications for research aimed at monitoring populations of these species?
(3) what factors cause observed differences in California gnatcatcher densities, and can we identify those habitat characteristics which determine whether areas act as population sources vs. sinks?

<u>What factors influence patterns of dispersal by California gnatcatchers?</u>

When the California gnatcatcher was first listed as a federally Threatened species, available information suggested that its specialized dependance on coastal sage scrub vegetation would make it particularly vulnerable to urban fragmentation of existing tracts of natural habitat (Atwood 1993). Certainly it has proven true that breeding territories of gnatcatchers are almost invariably located in coastal sage scrub, but behavioral observations also have found that, especially during the fall months, dispersing juvenile may occur in various "atypical" types of habitat, ranging from disturbed and ruderal areas dominated by ornamental tree and shrub species to grassland, chaparral or riparian habitats. It is during this period of fall dispersal that juvenile gnatcatchers appear most likely to move among patches of coastal sage scrub habitat, including at least occasional crossings of vegetation types that are seldom used for nesting activities.

Such behavior raises the question of how to identify areas that might function as dispersal corridors but which are not occupied by breeding pairs. Attempting to identify dispersal corridors through field work aimed at directly detecting actual dispersal events is simply not logistically practical. A far better approach is to attempt to understand the general principals that influence the species' dispersal behavior, and then apply these principals to the various landscapes where planning decisions require identification of suitable corridors and linkages among core components of a habitat reserve system.

The frequency of among-patch movements, the distances which dispersing gnatcatchers typically move away from their natal territories, and the types of vegetation that function as barriers to movement might legitimately all be viewed as "limiting criteria" affecting the design of a coastal sage scrub reserve network. Patches of suitable and occupied habitat that exceed the distance likely to be traversed by a juvenile gnatcatcher, or which are separated by habitat types that act as barriers to movement, are, for all intensive purposes, isolated islands. For instance, although addressed by a single EIR/EIS document, gnatcatcher populations in the central and coastal subareas of the approved Orange County NCCP likely function as isolated units due to the intervening expanse of urban and agricultural development (although both subareas have relatively broad connections with other NCCP regions in Riverside County or southern Orange County, respectively). Definition of the metapopulation structure has profound impacts on predictions of population viability under various scenarios (Akçakaya and Atwood 1997).

The preliminary analysis presented here suggests that patches of coastal sage that are located within 5 km of each other are likely to be close enough to allow some interchange of gnatcatchers during juvenile dispersal, but that most birds are unlikely to move more than 3 km from their natal site. While available data do not suggest serious genetic consequences, rates of interchange between many habitat patches are likely so low that "rescue" from local extinction through immigration cannot be readily assumed.

In this context, juvenile survivorship is also important. If mortality of dispersing juveniles proves greater in fragmented, edge-characterized, landscapes than in more natural areas, then even if a species is capable of moving considerable distances during dispersal, increased juvenile mortality in a fragmented landscape would eventually cause the population to decline.

Obtaining data on gnatcatcher dispersal behavior is a difficult and labor-intensive process. Banding efforts must focus not on the relatively easily-captured territorial adults but instead on nestlings and recently-fledged juveniles still associated with their natal territories. In coastal Orange Co. we obtained approximately 13 following-year band recoveries (resightings) for every 100 fledged, banded juveniles, suggesting that any studies of gnatcatcher dispersal behavior that fail to include a large and intensive marking and resighting effort are likely only to yield anecdotal data of questionable scientific value.

<u>What factors influence year-to-year fluctuations in California gnatcatcher population sizes, and what are the implications for research aimed at monitoring populations of this species?</u>

Our results demonstrate that California gnatcatcher population estimates may exhibit relatively dramatic year-to-year fluctuations independent of anthropogenic habitat destruction (fire or development). At this point the best working hypothesis appears to be that harsh winter weather conditions, most likely including a combination of prolonged periods of rain and cold temperatures, may occasionally increase mortality rates of both adults and juveniles. Population declines between the 1994 and 1995 breeding seasons on the Palos Verdes Peninsula and in coastal Orange County appeared to be correlated with an unusually wet and cold winter.

To date, we have found no evidence of pronounced annual differences in reproductive success, and thus hypothesize that environmental factors affecting survivorship are more likely to determine population trends than factors influencing reproductive success. However, our study has not been maintained long enough to carefully evaluate the potential effects of drought conditions on reproductive success. Drought was early suggested as possibly causing low gnatcatcher population levels in southern California in the early 1990's, and various authors have suggested that at least some winter rainfall patterns may promote lush plant growth and increased insect abundance which might result in higher reproductive rates (Ogden Environmental and Energy Services Co. 1992). While we concur that this is a reasonable hypothesis, our results have not yet documented significant annual differences in reproductive success.

Estimates of annual differences in reproductive success and survivorship are important components in most population models. Using preliminary data from the coastal Orange County and Palos Verdes studies, Akçakaya and Atwood (1997) concluded that "results point to a need to better estimate two groups of ecological parameters. One group is the vital rates (especially fecundity) and the frequency and amount of change in vital rates caused by catastrophes. The other group includes density dependence [sic] parameters, including Allee effects. Detailed data on vital rates may also help estimate these parameters, for example by comparing fecundities in regions with different density of gnatcatchers. Such a data set may also help link the vital rates to habitat suitability, eliminating one of the stronger assumptions of our model (that vital rates are the same for all populations)". As additional years of demographic data are accumulated, improved estimates of these parameters may be used to refine this initial model and improve its predictive power.

What factors cause observed differences in California gnatcatcher population densities, and can we distinguish habitat characteristics which determine whether areas act as population sources vs. sinks?

Perhaps the most difficult aspect of habitat conservation planning aimed at addressing the ecological requirements of California gnatcatchers is that not all areas of coastal sage scrub appear to be equally suitable for the species. Although this broad vegetation category may be readily classified by a plant ecologist or mapped by a GIS photointerpreter, the fact still remains that some areas of scrub support relatively dense populations of gnatcatchers, while in others the species occurs only sparsely or not at all. Are areas where gnatcatchers occur at low densities just as likely to contribute to population viability as areas where the species is densely distributed? Or are areas that support low densities of gnatcatchers population "sinks", where survivorship and recruitment are too low to maintain larger population sizes?

These questions have profound practical ramifications, especially since many dense gnatcatcher populations occur on extremely valuable private real estate, and many areas of coastal sage scrub with low gnatcatcher population densities coincide with regions proposed for NCCP habitat reserves. Is the NCCP effort succeeding only in protecting areas that ultimately will be unable to sustain healthy populations of the program's flagship species?

Our data are still inadequate to answer these questions, but we note with interest that while we found no significant difference in reproductive success (as measured by the number of fledglings produced annually per pair) between study sites that support low and high densities of breeding gnatcatchers, there was a difference in the frequency with which pairs successfully raised two broods between areas of coastal sage scrub dominated by *Artemisia* vs. areas dominated by *Salvia*.

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APPENDIX A

Banding Summary, 1992 - 1997
[FOLLOWING PAGES]

CAGN = California gnatcatcher

<u>Color Codes</u>
sequence: bird's right leg – bird's left leg; proximal color listed first,
distal color listed second
slash / designates 2-color split band (listed proximal / distal)
M = USFWS band; B = black; DB = dark blue; LB = light blue; DG = dark green;
LG = light green; Y = yellow; R = red; W = white; P = mauve; O = orange

<u>Age Codes</u>
AHY = after hatching year on date of banding
HY = hatching year on date of banding
L = nestling (or fledgling incapable of sustained flight)
U = unknown

<u>Location Codes</u>
Refer to topo-based grid system (available from Atwood by request)

ETS05
Appendix V
Conservation and Management of Coastal Sage Scrub

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Conservation and Management of Coastal Sage Scrub

Background and objectives

The aim of this task was to update the California Gnatcatcher Population Viability Analysis (PVA) model that was developed in a previous project. The previous model was published in the journal *Conservation Biology* (Akçakaya and Atwood 1997). The main body of the report describes the changes that were made to this previous model, using two years of new data that became available since the publication of the 1997 article.

Methods

The Model

The model is a spatially explicit, stage-structured, stochastic model of the California Gnatcatcher metapopulation in central and coastal Orange County. The model development (Akçakaya and Atwood 1997) started with a compilation of habitat data on vegetation and topography, and demographic data on survival, reproduction and dispersal of the species. The habitat data included raster maps of coastal sage scrub vegetation, elevation, slope, aspect, distance from grasslands, distance from trees and distance from wetlands. These data were organized by a geographic information system software, and combined with locations where gnatcatchers were observed.

These data were then used in a stepwise logistic regression, in which the gnatcatcher observations were the dependent variable, and values from habitat maps were independent variables. The result of this regression was a value (between 0 and 1) for each cell in a raster map. The value gave the probability of finding a gnatcatcher pair at that location, and thus reflected the suitability of the habitat.

The resulting habitat suitability map was then validated, by estimating the regression function from half the landscape, and using this function to predict the habitat suitability for known locations in the other half. The validated habitat suitability map was analyzed to calculate the spatial structure of the species' metapopulation (i.e., the number, size, carrying capacity and location of its subpopulations), based on the distribution and quality of the habitat.

At the population level, the model for the California Gnatcatcher incorporated demographic data on survival, reproduction and environmental variability, for each population inhabiting a habitat patch. Most of the demographic data used in the model were collected by banding studies (Atwood et al. 1995, 1996, 1999). At the regional (metapopulation) level, it incorporated data on spatial factors that are important determinants of the risk of decline, including dispersal among patches, catastrophes (Akçakaya and Baur 1996), and spatial correlation of environmental fluctuations among the patches (LaHaye et al. 1994).

The model was implemented in RAMAS GIS 3.0, which is designed to link landscape data from a geographic information system with a metapopulation model (Akçakaya 1998). For other applications of the program, see Akçakaya et al. (1995), and Akçakaya & Raphael (1998); for reviews see Kingston (1995) and Boyce (1996).
The following sections summarize the main features of the model, and describe the

changes to the model from Akçakaya and Atwood (1997; see the Appendix).

Habitat and Census Data; Habitat Suitability Map; Patch Structure

There were no changes to the habitat variables and census data that formed the basis of our analysis. Thus, we used the same the habitat suitability function and the same habitat suitability map as in Akçakaya and Atwood (1997). We also used the same values for the *Threshold HS* parameter and for the *Neighborhood distance* parameter.

The only change in the patch structure was a "protected area mask" we applied to the habitat suitability map. This mask was derived from the reserve coverage in the ArcInfo export file ccres7-10-98.e00 (dated 11/13/98 10:25; size: 1,599,382 bytes) received on a CD from the County of Orange. This coverage corresponds to the "Proposed Habitat Reserve System Map" (Figure 12 of the *Draft EIR/EIS for Central/Coastal NCCP*). We used this map to mask non-reserve areas while letting the proposed reserve areas to show through.

Carrying Capacities and Initial Abundances

We changed the model to include only females, because pooling sexes together in a matrix model may overestimate viability compared to an individual-based model of the same population. Thus, for calculating carrying capacities based on habitat, we used half the scaling constant that we have used in the 1997 paper. We multiplied total habitat suitability with 0.107 to calculate the carrying capacity (K) of each patch (we excluded patches with K=2 females). We used the same proportion of K (80%) for the initial abundances as in Akçakaya and Atwood (1997).

Because of these changes, these parameters (initial abundance and carrying capacity), as well as all results of the model are now expressed in terms of the number of female gnatcatchers. However, we estimated the survival rates using pooled data, because this increases accuracy, and because there are no significant differences between the sexes in terms of their vital rates.

Stage Structure

We modeled the dynamics within each patch with a stage-structured, stochastic matrix model with two stages (juveniles and adults). In parameterizing this stage-structured model, we made the same 5 basic assumptions as in Akçakaya and Atwood (1997), and used the same matrix structure:

$$\begin{bmatrix} P_{JB}M & S_aM \\ S_j & S_a \end{bmatrix},$$

where S_a is survival rate of adults; S_j is survival rate of juveniles; P_{JB} is proportion of last year's juveniles that are breeders this year; and M is maternity or fertility (number of fledglings per breeder). As in Akçakaya and Atwood (1997), the two elements in the first row of the matrix are fecundities: adult fecundity (F_a) is equal to $S_a{\cdot}M$; juvenile fecundity (F_j) is equal to $P_{JB}\cdot M$. Note that M is the number of female fledglings (daughters) per breeding female, but not total fledglings per female or total fledglings per pair. In calculating M, we assumed 1:1 sex ratio at birth.

We updated the estimates of these parameters in several ways. First, we used new data from 1997 and 1998, increasing the number of years from 3 to 5. Second, we were able to estimate more of the parameters from Orange County, rather than Palos Verdes.

This required some additional assumptions, which are explained below. Third, we refined the parameter estimates for previous years using data that were updated due to the continuing process of data entry and editing (Atwood et al. 1999).

In the previous model (Akçakaya and Atwood 1997), we have used survival data from Palos Verdes peninsula. Because we are building a model for Orange County, in this study we tried to estimate all the parameters based on data from Orange County. The data from Palos Verdes had two advantages. First, because Palos Verdes is a relatively isolated area, dispersal out of the study area was probably minimal, making survival estimates more accurate. In Orange County, dispersal of juveniles out of the study area may cause a biased estimate of juvenile survival rate. We corrected this bias by adding 0.1515 to each year's estimate of S_j. The value 0.1515 is the mean difference between S_j estimates from Orange County and Palos Verdes for 1993-1997.

The second advantage of the Palos Verdes data was also related to its relative isolation, which made it possible to accurately estimate the proportion of juveniles that became breeders each year. Similar data were not available from Orange County. Data from Palos Verdes shows that the proportion of *surviving* juveniles that become breeders ranged from 0.47 to 1.00 between 1993 and 1996 (Table 1). Using these proportions, the parameter P_{JB} would be calculated as follows:

$P_{JB} = 0.8448 \cdot S_j$ for non-catastrophe years, and

$P_{JB} = 0.4667 \cdot S_j$ for catastrophe years (see below for modeling catastrophes).

Table 1. Proportion of surviving juveniles that became breeders in Palos Verdes

Year	Number of surviving juveniles	Number that became breeders	Proportion of survivors that become breeders
1993	21	13	0.6190
1994	15	7	0.4667
1995	22	21	0.9545
1996	15	15	1.0000
Average			0.7671
Average for 93, 95, 96 (non-catastrophe years)			0.8448

However, there is some uncertainty on whether there are any non-breeding juveniles. It may be that juveniles that have not paired prior to the beginning of their first breeding season (and thus recorded as non-breeding in the census) may wander around as floaters until they encounter and unpaired bird, at which time they start to nest. We believe that most juveniles (1st year birds) make at least one nesting attempt. Therefore, we decided to assume that all surviving juveniles breed, i.e.,

$P_{JB} = S_j$.

One potential source of bias is that these birds may nest later than previously paired birds, which might translate to fewer nesting attempts per year for some first year birds and, presumably, a smaller number of fledglings produced. We recommend that if this model is used for decision-making (for example by comparing alternative management options), the comparisons are done with different values of P_{JB} to ensure that the model results (e.g., rank of management options) are not overly sensitive to this parameter. In addition, the same comparisons should be made with upper and lower bounds of all other parameters, as discussed in Akçakaya and Atwood (1997). Relative risk-based results (such as difference in risk between two options), especially when comparisons are made for each set of assumptions, are much less sensitive to uncertainties in model parameters (Akçakaya and Raphael 1998).

The estimation of the elements of these stage matrices is given in Table 2. The adult survival from 1994 to 1995 was substantially lower than those for other years. This corresponds to observations that suggest a sharp region-wide decline (Atwood et al. 1996, 1999; Erickson & Pluff, 1996; Chambers Group and LSA Associates, unpubl. data). Thus we used two vital rates (the adult survival and proportion of juveniles becoming breeders) from 1994 for modeling catastrophes. Unlike the data used in Akçakaya and Atwood (1997), other vital rates (particularly juvenile survival) for 1994 were not lower than other years. Thus, we did not use other parameters when modeling catastrophes.

Table 2. Stage matrix parameters

Year	M	$S_{j(OC)}$ [b]	S_j [c]	$S_j \cdot M$	S_a	$F_a{=}S_a{\cdot}M$
1993	1.9444 [a]	0.0625	0.2140	0.4161	0.6875	1.3368
1994	1.3500 [a]	0.1548	0.3063	0.4135	0.4667 [d]	0.6300 [d]
1995	1.3289	0.1871	0.3386	0.4500	0.6790	0.9024
1996	1.1447	0.1131	0.2646	0.3029	0.6596	0.7550
1997	1.2961	0.1327	0.2842	0.3683	0.5393	0.6990
Average	1.4128	0.1300	0.2815	0.3902	0.6414 [e]	0.9233 [e]
St. deviation	0.3079	0.0467	0.0467	0.0568	0.0690 [e]	0.2887 [e]

[a]*These data are from Palos Verdes, because data are not available from Orange County for these years. All other data are from Orange County.*

[b]*These data from Orange County are assumed to be biased because of juvenile dispersal; they are corrected in the next column.*

[c]*Corrected by adding 0.1515 to $S_{j(OC)}$ to represent dispersal of juveniles.*

[d]*These data are used to model catastrophes.*

[e]*These averages and standard deviations do not include data from 1994, which were used to model catastrophe years.*

Environmental and Demographic Stochasticity

We modeled environmental stochasticity by sampling the set of vital rates for each time step (year) from lognormal distributions (see Akçakaya and Atwood 1997). For adult survival and fecundity, we estimated the standard deviations based on four transitions (1993-94, 1995-96, 1996-97 and 1997-98; see Table 2). We used the 1994-95 transition to model catastrophes (see below), so we did not include this transition in estimating the standard deviations of F_a and S_a.

The observed variances include variance components due to demographic stochasticity and sampling variation, which must be subtracted in order to obtain accurate estimate of variance due to natural variability (environmental stochasticity). However, the methods for separating variance components in vital rate estimates are currently being developed and there are few published references on this topic. In addition, because of the short time series of vital rates (only 4 transitions, excluding the one used to model catastrophes), the observed variance may not be representative of the true amount of natural variability. Thus, for the time being we have decided to use the observed variance to model environmental stochasticity.

We modeled demographic stochasticity as described in Akçakaya and Atwood (1997).

Catastrophes, Density Dependence and Metapopulation Dynamics

One type of catastrophe that may affect species living in coastal sage scrub is fire. We modeled fires as described in Akçakaya and Atwood (1997). Another type of catastrophe with direct impact on gnatcatcher populations may be extreme weather conditions, such as those that may have characterized the winter of 1994-95. We modeled these catastrophes as described in Akçakaya and Atwood (1997), except for the differences in vital rate estimates discussed above.

There is some evidence that the populations may be regulated by "contest" (i.e., Beverton-Holt) or "scramble" (i.e., Ricker) type of density dependence. The long-term deterministic growth rate (λ) predicted by the average vital rates is 1.00 for all years and 1.04 for non-catastrophe years. These might indicate a population that is stable in the long-term, which is consistent with density-dependent regulation. In addition, the long-term deterministic growth rate (λ) predicted by the vital rates in 1994 (the catastrophe year) is 0.88, which is followed by 1.13 for the next year. These might indicate a "bounce back" after the low abundance caused by the catastrophe year, which is also consistent with density-dependent regulation. However, there are no independent estimates of abundance for each year, and the data series is too short to estimate density dependence in vital rates. Thus, we modeled density dependence with the ceiling model, as described in Akçakaya and Atwood (1997) for the medium-parameter model. The ceiling model allows the populations to fluctuate independent of the population size (N), according to the vital rates and their standard deviations, until the population reaches the ceiling. The population then remains at this level until a population fluctuation takes it below the ceiling. This model also allows catastrophes to be modeled with decreased vital rates (as described above), thus it gives more conservative (precautionary) results. However, we recommend that if this model is used for decision-making (for example by comparing alternative management options), the comparisons are done with different types of density dependence to ensure that the model results (e.g., rank of management options) are not overly sensitive to this parameter.

We modeled Allee effects with population-specific extinction thresholds, as described in Akçakaya and Atwood (1997). Parameters related to dynamics at the metapopulation level include the interdependence of environmental fluctuations among populations, and patterns of dispersal. We modeled these factors as described in Akçakaya and Atwood (1997).

Results

We used the same methods as in Akçakaya and Atwood (1997) to run simulation and to analyze and report the results.

Habitat suitability map

As described above, the only change in the habitat suitability map was due to a "protected area mask" we applied to the habitat suitability map. This mask was designed to mask non-reserve areas while letting the proposed reserve areas to show through. Thus, the new habitat suitability map included only the protected habitat, assuming that the non-reserve areas will eventually become unsuitable for nesting, although they can be used for dispersal among reserve areas. This new habitat map is shown in Figure 1.

Patch Structure

Given the habitat map, and the (medium) parameter estimates described above, the program found 9 habitat patches (clusters of suitable cells within the neighborhood distance of each other). The 2 largest patches made up about 86% of the total area of all patches (Table 3). The total carrying capacity was 795 females, or (at stable distribution) 329 adult females. The total initial abundance was 636 females, or 263 adult females.

Table 3. The patch structure: area, carrying capacity (K) and initial abundance (N[0]) of patches

Patch	Area (km^2)	% area	K	N[0]
1	0.5	0.52%	4	3
2	8.7	9.77%	71	57
3	0.6	0.64%	4	3
4	22.2	24.89%	199	159
5	0.7	0.76%	5	4
6	0.4	0.48%	4	3
7	54.6	61.08%	494	395
8	0.9	0.96%	7	6
9	0.8	0.90%	7	6
Total:	89.4	100.00%	795	636

Viability

With the medium parameter estimates, the model predicted a substantial decline, but a low risk of extinction of the gnatcatcher populations. The risk of falling below the metapopulation threshold of 30 females within 50 years was about 10%. Although the extinction risk was low, the risk of a substantial decline was high. For example, the risk that the metapopulation will decline by 80% or more from the initial abundance within 50 years was about 56% (Figure 2). Risk of 80% or more decline is the risk that there will be 127 or fewer females left in this metapopulation.

Discussion

Because of the uncertainty in most model parameters, and the sensitivity of results to these uncertainties, we suggest that the results should not be interpreted in absolute terms. Specifically, it would be inappropriate to use the results of this model to conclude that gnatcatcher populations in Central/Coastal Orange County are either threatened by extinction or secure from such a threat. There is too much uncertainty to predict with

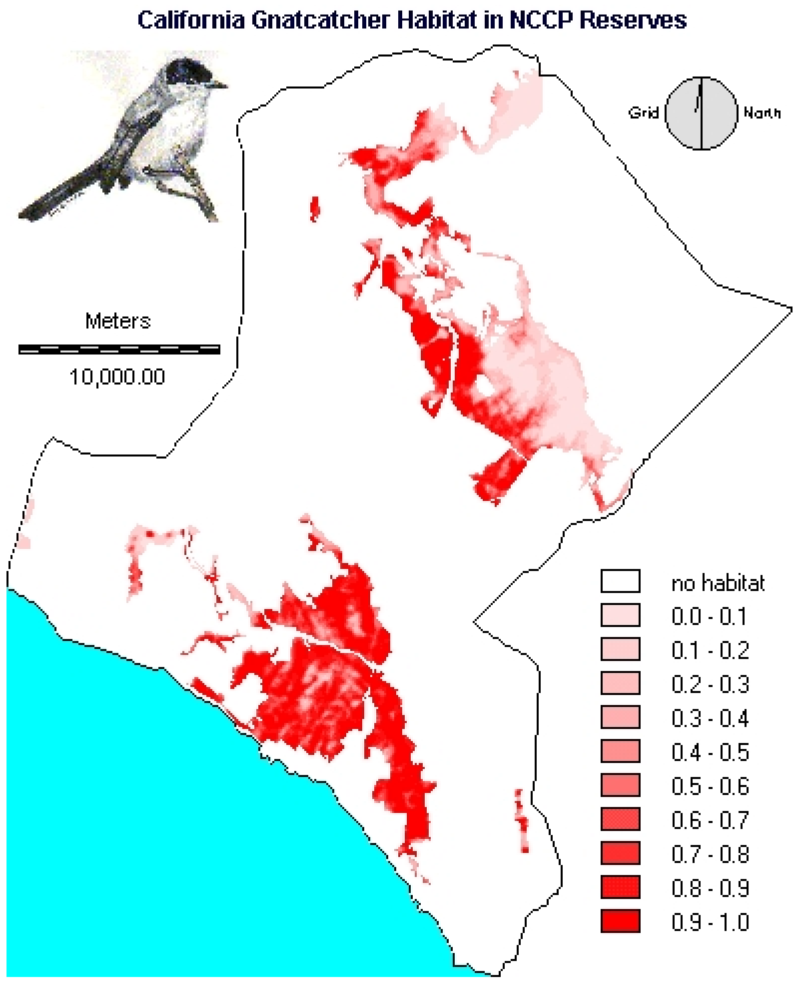

Figure 1. Habitat suitability map for the California Gnatcatcher in the Central and Coastal Orange County NCCP reserve system.

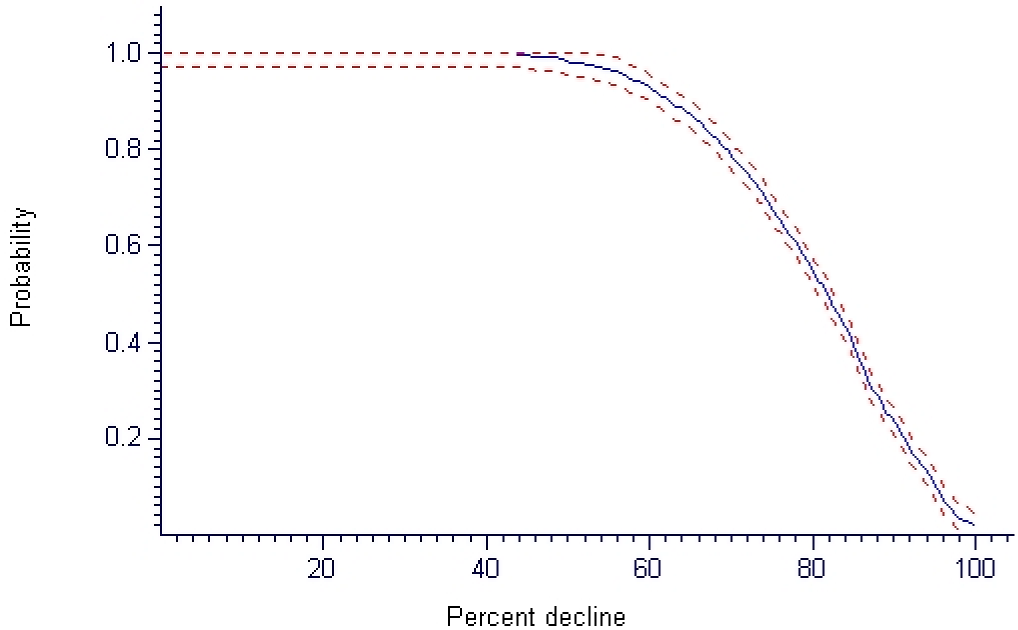

Figure 2. Risk of decline curve: each point on the curve gives the probability that the total abundance will decline, within the next 50 years, by the percent amount indicated on the *x*-axis from the initial abundance of 636 females. Thus, 80% corresponds to 127 or fewer females left in the metapopulation.

confidence what the population size will be in 50 years, or what the risk of extinction might be. Despite this uncertainty, we believe the model can have practical application in several areas. The potential applications of the model (based on Akçakaya 1999) are discussed below. These applications also indicate future research directions. We believe that the research directions outlined below will lead to a set of practical tools for evaluating options for the management and conservation of the coastal sage scrub community.

Planning Fieldwork and Refining Models with Model-driven Field Research

Most parameters of a PVA model are known with a certain amount of uncertainty. Further fieldwork may yield data to narrow down these uncertainties and thus make model predictions more accurate and reliable. Analysis of the sensitivity of model results to various parameters provides guidance about what kind of data would be most efficient in terms of making the model predictions more reliable.

Using a model for management and conservation is an iterative process involving (in an annual cycle) field research, parameter estimation, analysis and monitoring. Field research provides data for estimating model parameters; analysis of the model provides guidance for further field research as well as for management; monitoring allows independent checks of the model predictions and the evaluation of the effectiveness of management actions. The parameter estimation and analysis (including sensitivity analysis) steps must be carried out at least once a year to incorporate data collected during that year. This will facilitate efficient use of limited time and resources available for fieldwork and management. It will allow more accurate estimation of the most important model parameters, and increase the reliability of the model.

Expanding Geographic Coverage to Southern California

An important limitation of the model is its geographic coverage. The coastal sage scrub in the study area may be connected to similar habitat in southern Orange county and elsewhere. Thus, the limits of the study area in central and coastal Orange County are somewhat arbitrary. One of potential improvements to the model involves expanding it to include the populations of California Gnatcatcher in other areas.

The data for central and coastal Orange county is quite detailed, and it may be difficult to find as detailed data for other parts of the region. The accuracy of the habitat maps in other parts of the region may be estimated by using the current study area as a standard. This comparison will provide a basis for making necessary corrections to a larger, regional map.

The larger map may then be used to determine the spatial structure of the metapopulations of the target species in a wide geographic area. This information can be used to expand the current metapopulation models to the whole region. This expansion will allow us to evaluate management options in other parts of the region.

Designing Reserves

Reserve design, especially in a region as crowded as southern California, is determined by a large number of biological, economical, political and social constraints. These constraints limit the number of feasible reserve configuration options. Metapopulation modeling can help provide scientific guidance to the process of reserve design by showing the environmental managers the ecological consequences of each option. This can be done by calculating the risk of decline for selected species under each reserve design option. Each reserve design option will then be associated with an economic (cost) and an ecological (risk of decline) consequence. This approach can also be used for other aspects of reserve design, for example designing habitat corridors and other connecting habitat, or adding small, “stepping-stone” habitat patches to existing reserves.

Testing Management Options

In principle, all possible management actions can be represented as changes in habitat suitability or demographic parameters, once the effect of these management actions are described in terms of model parameters. The consequences of these changes are estimated by the model in terms of the viability of the species, and then used to rank alternative management actions, to prioritize conservation measures, and to evaluate the relative importance of different parameters.

Scarcity of reliable demographic data (and the resulting model uncertainty) is a common problem for PVAs. However, the model can address questions about management options despite its uncertainties. This is because the model results are much more reliable if interpreted as relative predictions (relative to a no-action scenario or to other management options), than if interpreted as absolute predictions. Results of various sensitivity analyses indicate that even in cases with considerable model uncertainty, the habitat-based risk assessment approach is sensitive to the effects of alternative management actions (e.g., see Akçakaya and Raphael 1998). Thus, it can be used to compare and rank management alternatives in terms of their effect on the viability of the species studied.

Assessing Human Impact

Assessment of human impact can be done in a way similar to the evaluation of management options. Each impact affects the population in a specific way. These effects can be quantified as changes in model parameters or structure. For example, habitat loss may decrease the carrying capacities of affected habitat patches; fragmentation can change the spatial structure of the metapopulation; pollution and widespread degradation of habitat quality may affect vital rates such as survival and fecundity; geographic barriers may lead to both fragmentation and a decrease in connectivity (dispersal rates among patches).

Reserve Design and Management from a Multi-species Perspective

The habitat-based metapopulation modeling approach described above can be applied to a list of selected (e.g., "indicator", threatened or sensitive) species. This results in habitat suitability maps, and metapopulation models for all species in the list. The results of the model simulations are used to estimate the risk of extinction or decline of the species in the whole region, as well as the importance of each location for the viability (persistence) of the species. Each of the individual habitat suitability maps can then be combined into a single aggregate map (a "multi-species conservation value" map) that expresses the worth, in conservation terms, of the locations. The habitat suitability maps can be combined mathematically by using a weighted average of all of the maps (Akçakaya 1999).

Conclusion

Habitat Conservation Plans, as well as plans for the management and design of multiple species reserves, will work only if they are based on sound science. One of the most powerful scientific tools that land managers and decision-makers can use is population viability analysis (PVA) of selected species. These methods can be used to aid various types of decisions in the design and management of multi-species reserves. They can be used to guide fieldwork in order to use resources in the most efficient way. They can support reserve design decisions with a science-based comparison of the design options with respect to their ecological and economic consequences. They can be used to evaluate management options and impacts in terms of their effect on the viability of selected native species. Finally, they can be used to identify ecological "hot-spots", i.e., areas of high conservation value from a multiple species perspective.

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Appendix VI

RAMAS® Ecological Risk Model for Desert Tortoise

Phase II: Assessing Fragmentation and Predation Effects

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RAMAS® Ecological Risk Model for Desert Tortoise

Background and objectives

The goal of this project was to build an assessment tool for the evaluation the population-level risks to the desert tortoise from utility transmission line siting or modification, or from maintenance operations associated with transmission lines in the Mojave Desert of California. Specifically we examined factors affecting the long-term viability of the desert tortoise in California, Utah, Nevada, and Arizona using a stochastic metapopulation model. This report builds on Phase I results of this two-phase project. For this assessment we used RAMAS GIS 3.0, which was developed with partial funding from both Electric Power Research Institute (EPRI) and Southern California Edison (SCE) in past research on methods for evaluating quasiextinction risks to threatened populations. Phase I developed the initial estimates of demographic and geographic metapopulation parameters from the available data, chiefly from Goffs and Bureau of Land Management (BLM) study sites. Phase II expanded the Geographic Information Systems (GIS) portion to incorporate detailed habitat information from the University of California Santa Barbara (UCSB) Gap database, which was partially funded by SCE, the USGS National Gap database, and the Mojave Desert Ecosystem Database Project. In addition, we customized the RAMAS GIS model to address specific ecological issues, e.g. raven predation, utility activities such as maintenance, construction and siting.

Current Trends

The desert tortoise, federally listed as endangered, is impacted by both extrinsic (e.g. habitat destruction/degradation, drought) and intrinsic (e.g. low juvenile survival, delayed maturity) factors. The greatest threats to the tortoise and its long-term survival appear to be human intrusion in the desert tortoise habitat. Long-term data indicates that the populations of this species are declining, although some regions appear more vulnerable than others.

A regional-scale metapopulation model for the desert tortoise is an excellent tool to address long-term management and conservation issues. Such a model includes: length/age-specific demographic parameters; abundance estimates for Mojave Desert tortoise populations; estimates of annual variability in demographic parameters; environmental stochasticity; density dependence; and the effects of impact factors such as predation or habitat destruction/loss. Based on the available demographic data, we constructed such a stochastic, stage-based metapopulation model for the desert tortoise, with environmental variability, density dependence, and distinct sub-populations. This model was spatially-explicit and based on detailed geographic data incorporated from the USGS National Gap database and other public sources. Tortoises west of the Colorado River differ ecologically and genetically from populations east of the river and are currently listed as threatened by the USFWS (Luke et al. 1991). So, for this study we included only those populations that were west of the Colorado River, in California, Nevada, Utah, and Arizona.

Life History

The desert tortoise is a long-lived herbivore restricted to arid habitats in California, Nevada, Arizona, Utah and Northwestern Mexico. Desert tortoises spend 98% of their time in burrows (Luke 1991), which they excavate and defend, emerging in the spring to feed, mate and lay eggs. Most desert tortoises reach sexual maturity at approximately 180mm in carapace length (i.e., 8-20 years of age). Reproductive output of females varies from 0-3 clutches per season with 1-14 eggs per clutch depending on winter rainfall and forage availability. Regional abundance estimates vary. In Western Mojave some declines in desert tortoise numbers have been documented. In other regions, such as the Eastern Mojave, populations appear to be stable, i.e., neither increasing nor decreasing in size. Tortoises move extensive distances for foraging and finding mates, but freeways are deadly for the tortoise and restrict these movements (Luke 1991; Desert Tortoise Recovery Team 1994' Ruby et al. 1994). The fundamental problem is that the desert tortoise is widely distributed, long-lived and has delayed sexual maturity, making this species vulnerable to human impact and habitat destruction and loss.

Methods

The goal of this project was to examine factors affecting the long-term viability of the desert tortoise in California, Utah, Nevada, and Arizona using a stochastic metapopulation model. Required for the model were data on annual rates of survival and reproduction, population abundance, dispersal probability and density dependence. Extensive mark-recapture studies have been conducted at the Goffs study site in California in the Eastern Mojave Desert. Much of the demographic data available on desert tortoise are from these studies. Additional studies have been conducted on Bureau of Land Management (BLM) Lands scattered throughout the range of the desert tortoise.

Annual Survival

The model requires estimates of the mean annual survival and growth for each life-history stage. In the following discussion, the annual survival (*s*) represents the mean probability that an individual in a stage class will survive a single time step, i.e., one year. The growth rate represents the probability that a surviving individual grows enough during a single time step, i.e., one year, to move into the next larger class. Thus, growth rate (*g*), in this case, is the proportion of surviving individuals that move to a higher class, while (1-*g*) is the proportion of survivors that remain in the same size class.

The desert tortoise population at Goffs, California has been extensively monitored since 1977. Table 1 lists the calculated survival rates for six size classes of female tortoises based on the mark-recapture data from Goffs (Doak et al. 1994). No data are available on the demographic rates for turtles smaller than 60mm in length. Growth rates for these size classes are shown in Table 2, also based on the Goffs data (Doak et al. 1994). We made an assumption in the model that the growth and survival rates for stage 1 are the same as that for stage 2. We also assumed that stage 0 represents one-year olds (yearlings) with the same survival rate as that of stage 2.

Fecundity

Fecundity in the model represents the number of offspring that survive to one year of age after hatching. There are some estimates of the number of eggs females produce annually also at Goffs, California (Turner et al. 1986; Turner et al. 1987). As Figure 1 illustrates, the number of eggs produced by a female desert tortoise is dependent on her carapace length. Females will lay 0-3 clutches annually with 0-14 eggs in each clutch. Table 3 shows the average number of total eggs and the average number of daughters (assuming a 1:1 sex ratio), based on the relationship shown in Figure 1, for the midpoint of each of the reproductive size classes assuming a maximum size of 260mm. In the model, the egg counts are multiplied by a factor representing survival for the first year of life, which produces a particular population growth rate (see Populations section).

Table 1. Annual survival rates (*s*) for six stages of desert tortoises based on mark-recapture data (From Doak et al. 1994).

Class		Maximum carapace length (mm)	mean	s.d.	n
2		60-99	0.716	0.232	8
3		100-139	0.839	0.176	8
4		140-179	0.785	0.147	8
5	*	180-207	0.927	0.071	8
6	*	208-239	0.867	0.129	8
7	*	>240	0.860	0.123	8

*reproductive age class
n=the number of site-data combinations for which separate estimates were made

Table 2. Annual growth rates (*g*) for five stage classes of desert tortoises based on mark-recapture data (From Doak et al. 1994).

Class		Maximum carapace length (mm)	mean	s.d.	n
2		60-99	0.208	0.268	6
3		100-139	0.280	0.158	11
4		140-179	0.287	0.261	9
5	*	180-207	0.269	0.187	10
6	*	208-239	0.018	0.037	18

*reproductive age class
n=the number of site-data combinations for which separate estimates were made

Table 3. The annual average number of total eggs per female and daughters per female based on the eggs vs. length relationship and the midpoint length of each reproductive size class.

Class	Maximum carapace length (mm)	Annual Mean number of eggs per female: Total	Annual Mean number of eggs per female: Daughters Only
2	60-99	0.00	0.00
3	100-139	0.00	0.00
4	140-179	0.00	0.00
5	180-207	6.13	3.07
6	208-239	8.57	4.28
7	>240	12.50	6.25

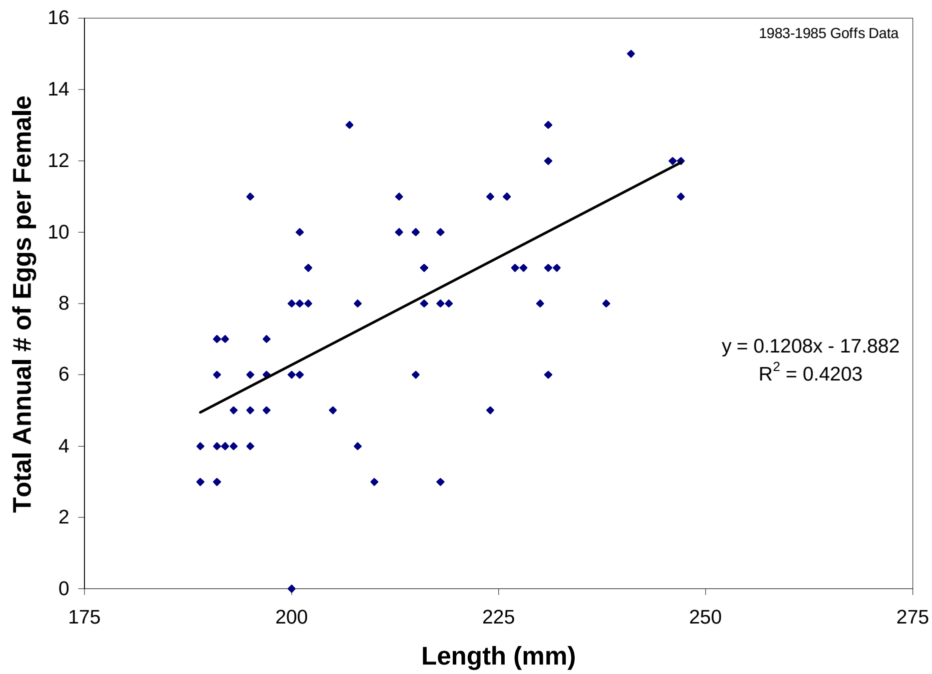


Figure 1. The number of eggs produced annually per female as a function of carapace length based on Goffs, California, data 1983-1985.

Habitat Suitability Analysis

In the Desert Tortoise Recovery Plan (1994) 12 Desert Wildlife Management Areas (DWMA's) were designated in six Recovery Units. We used these DWMA's as the basis for the location of the desert tortoise populations west of the Colorado River. These DWMA-based populations were large and comprised of both suitable and unsuitable habitat for the desert tortoise. Using a G.I.S. habitat suitability analysis based on the vegetation coverage, we estimated the area in square kilometers that was suitable for tortoises, shown in Table 4. We collected data on the vegetation types from the USGS National Gap Database (http://www.gap.uidaho.edu/gap) for each of the four states: California, Arizona, Nevada, and Utah. These coverages were downloaded as ArcInfo export files (*.e00) and imported into ArcView shapefiles. In ArcView, the vegetation coverage for a state was classified as either suitable or unsuitable based on tortoise food and habitat requirements. Habitat such as forests (large canopy cover), open water, urban areas, or agricultural land were considered unsuitable. Scrub or shrub-dominated habitats were considered suitable for the tortoise.

A complete G.I.S. coverage of major roads, i.e., county, state or federal highways was obtained from the Mojave Desert Ecosystem Database Project (http://mojave.army.mil/html/data/clg_100k/100kdlg.htm). (A similar but less complete road coverage was available for some of the states through the USGS National Gap Database. We chose the more complete G.I.S. data that covered the entire region of interest.) The Mojave Desert Ecosystem database also included G.I.S. coverages of the rivers and lakes, state boundaries and utility transmission lines. (G.I.S. coverages of the major roads and transmission lines were also obtained from Southern California Edison, but these data were not as comprehensive so they were not used in this analysis.) The coverages were downloaded as ArcInfo export files and imported into ArcView 3.0. The resulting ArcView shapefiles of each state were used as the basis for digitizing the DWMA-based populations of the two scenarios. The DWMA polygons were digitized directly into ArcView from a paper map based on the Desert Tortoise Recovery Plan (Desert Tortoise Recovery Team 1994).

These were digitized in ArcView (Figure 2) in two different ways. In the unfragmented scenario, we assumed that any populations that were contiguous represented a single population. With this assumption the 12 DWMA's become eight desert tortoise populations (Figure 2). Alternatively, in the fragmented scenario, we assumed that roads and rivers represented an insurmountable barrier to tortoise dispersal. The map, therefore, includes 26 distinct polygons or populations for desert tortoises in California, Utah, Nevada and Arizona (Figure 3).

Figure 4 illustrates the amount of habitat that was suitable or unsuitable for the populations in each state. In general, most (91%) of the habitat was designated as suitable for the desert tortoise's needs. Therefore, the area in square kilometers of each population, in the unfragmented (Table 4) and the fragmented (Table 5) metapopulations, was estimated based on the suitable habitat of the digitized coverages.

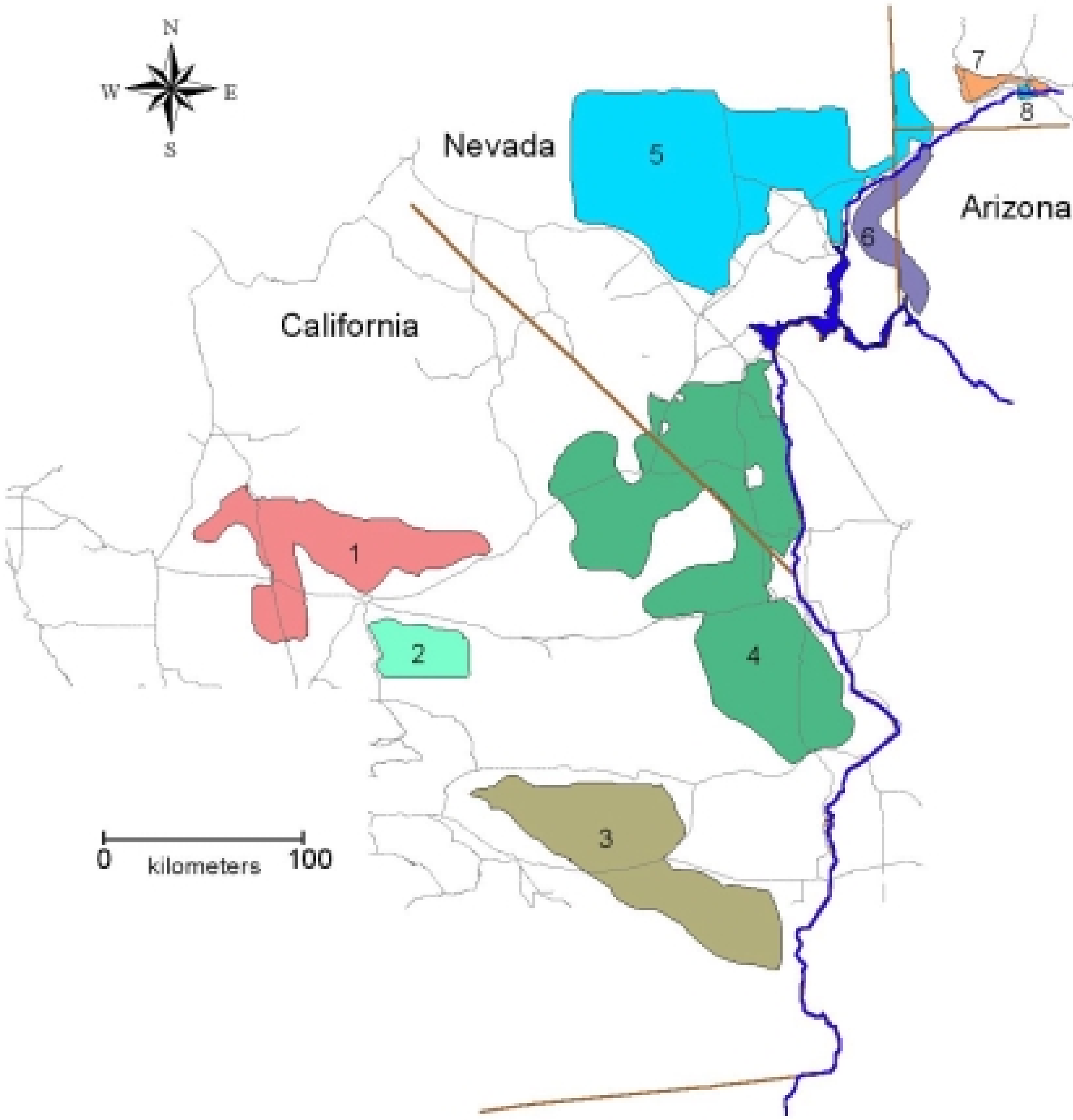


Figure 2. In the unfragmented scenario there were eight distinct desert tortoise populations west of the Colorado River.

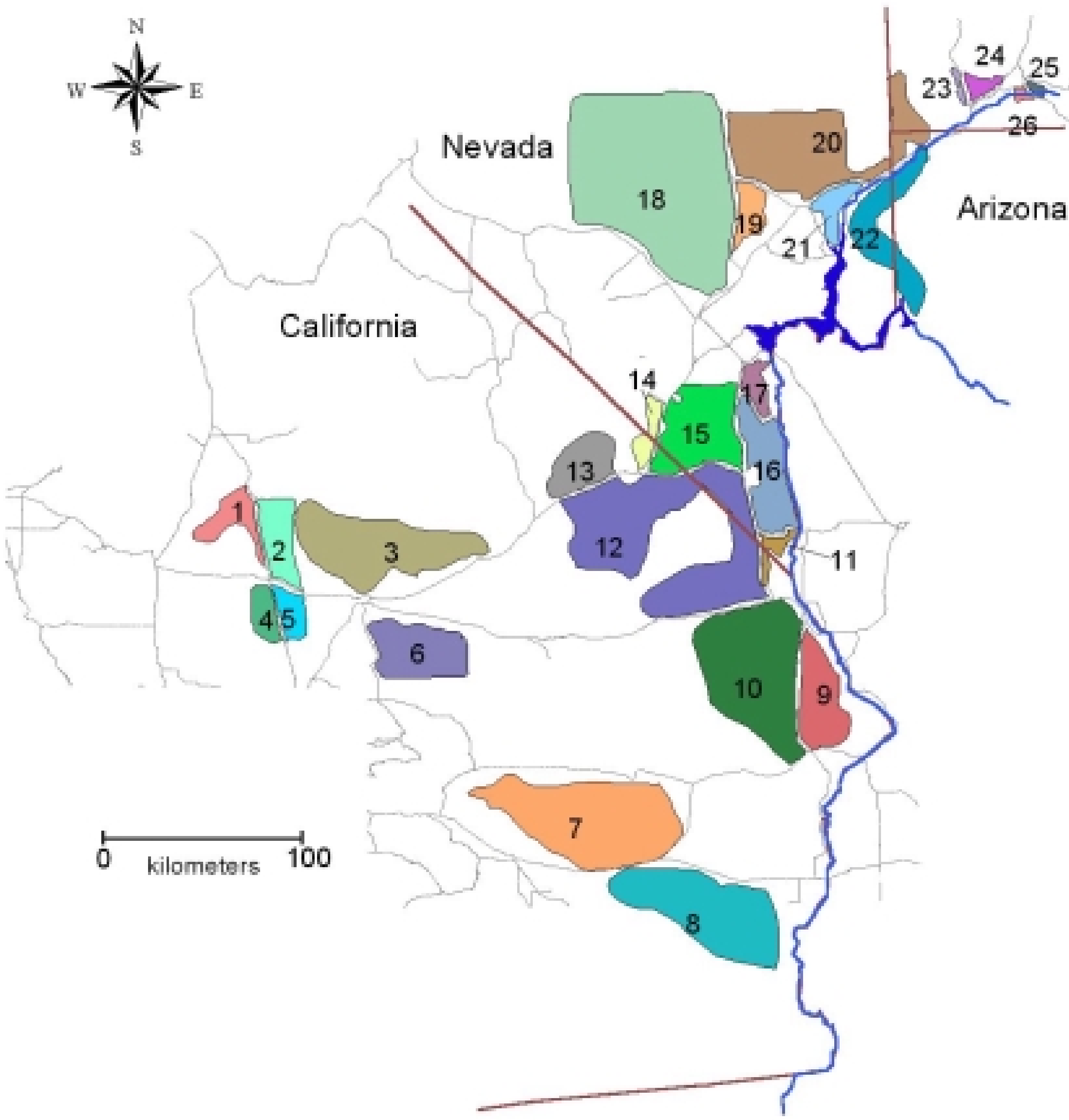


Figure 3. In the fragmented scenario there were twenty-six distinct desert tortoise populations separated by roads and rivers west of the Colorado River.

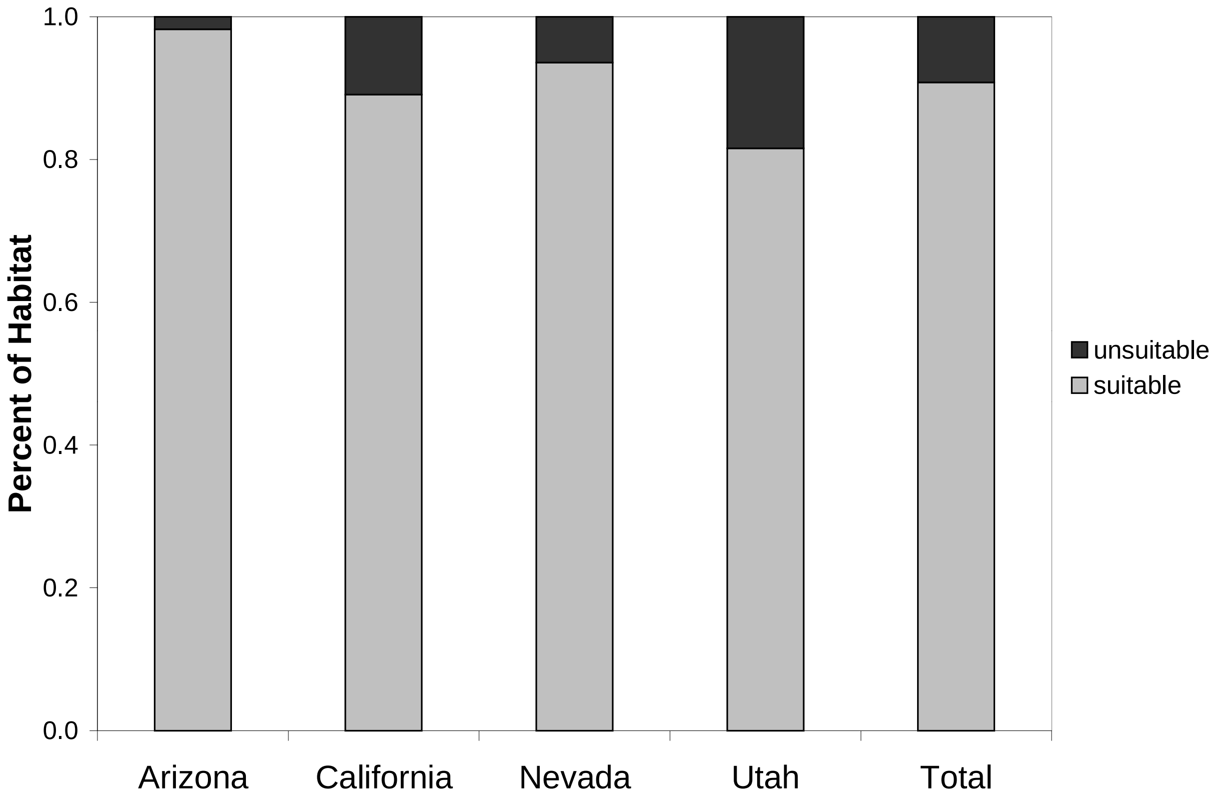


Figure 4. The area of habitat that was suitable or unsuitable (as a percentage of the total area) for desert tortoise in the populations found in each state.

Table 4. The population growth rate, area, density of tortoises, initial abundance of females and carrying capacity of females for each population in the unfragmented metapopulation.

Population	Growth Rate	Habitat Area (km^2)	Density ($/km^2$)	Initial Abundance	Carrying Capacity
1	1.020	4030.4	477.5	962,300	1,467,093
2	0.972	1,180.6	214.2	126,440	273,672
3	1.020	4,150.4	452.9	939,842	1,714,917
4	1.020	11,781.3	381.2	2,245,701	4,238,774
5	1.020	9,255.2	221.7	1,025,942	1,025,943
6	1.020	1,122.4	155.4	87,212	87,212
7	1.020	139.3	647.5	45,094	45,094
8	1.020	38.6	647.5	12,483	12,483

Table 5. The population growth rate, area, density of tortoises, initial abundance of females and carrying capacity of females for each population in the fragmented metapopulation.

Population	Growth Rate	Habitat Area (km^2)	Density ($/km^2$)	Initial Abundance	Carrying Capacity
1	0.914	481.1	406.6	97,804	211,183
2	0.916	661.2	205.9	68,070	268,857
3	1.020	2260.4	647.5	731,799	731,799
4	0.916	324.1	205.9	33,363	131,774
5	0.916	303.7	205.9	31,264	123,481
6	0.972	1180.6	214.2	126,440	273,672
7	1.020	2843.0	518.0	736,338	736,338
8	0.943	1307.4	311.3	203,504	978,579
9	0.972	1001.9	206.9	103,667	290,632
10	0.972	2803.6	206.9	290,091	813,272
11	1.020	163.5	716.6	58,563	63,926
12	1.020	3978.3	580.0	1,153,744	1,712,155
13	1.009	748.0	306.9	114,786	380,682
14	1.009	255.1	330.0	42,093	95,803
15	1.009	1475.2	330.0	243,419	554,020
16	0.847	1100.5	353.1	194,293	266,499
17	0.847	255.1	353.1	45,045	61,785
18	1.020	5915.5	233.1	689,445	689,445
19	1.020	362.1	233.1	42,201	42,201
20	1.020	2715.2	194.2	263,711	263,711
21	1.020	262.4	233.1	30,586	30,586
22	1.020	1122.4	155.4	87,212	87,212
23	1.020	30.8	647.5	9,965	9,965
24	1.020	67.2	647.5	21,767	21,767
25	1.020	41.3	647.5	13,362	13,362
26	1.020	38.6	647.5	12,483	12,483

Initial Abundance and Carrying Capacity

Using mark-recapture techniques for 60-day censuses on BLM plots, population density estimates were computed. These estimates are reasonable assuming: no immigration or emigration occurs during the study; no mortality or recruitment occurs during the study; marking animals does not influence their capture probability or mortality; and all animals have an equal probability of capture (Luke et al. 1991).

There were two sources of density estimates for these populations. Between 1977 and 1989, tortoises were captured and measured at 20 BLM plots scattered throughout the region. These captures were used to estimate densities. Small tortoises are difficult to locate and measure and low numbers of recaptures in the smaller size classes potentially inflates the population density estimates (Luke et al. 1991). Therefore, the densities of tortoises larger than 180mm in carapace length were considered the most reliable (Luke et al. 1991) and were used whenever available. In the Desert Tortoise Recovery Plan (1994), a range of densities is given for each the 12 regions. For populations that included parts of more than one DWMA, the average density of the individual DWMA's was chosen for the population.

An assumption was made that the sex ratio was one to one and, therefore, half of the population was females. The initial abundance for each population/polygon was either the average BLM density of tortoises >180mm, or the average BLM density of all tortoises, or the maximum of the DWMA density estimate (in order of preference) multiplied by the habitat area of the population and divided by two. For populations including more than one sampling area the average density was used for the initial abundance estimate. The initial abundance of females for each population is shown in Tables 4 and 5 for the unfragmented and fragmented metapopulations, respectively. The BLM maximum density estimate, if available, or the maximum DWMA density estimate was used to calculate the carrying capacity for each population, Tables 4 and 5.

Dispersal

O'Connor et al. (1994) measured marked tortoise movements and using minimum convex polygon technique estimated an average home range for both male and female tortoises of 27-34 hectares. There was a large amount of overlap (1-43%) among adjacent home ranges that suggests that these are not exclusive territories. In addition, on average 65% of the area enclosed within the home ranges measured was not utilized by the tortoises. Home range for females has been estimated as 15-21 ha and for males 23-53 ha (O’Connor et al. 1994). Tortoises never occupy the same exact area from year to year (O’Connor et al. 1994). Home range size is strongly predicted by food availability (O’Connor et al. 1994). Females maintain a more constant home range size under adverse conditions (O’Connor et al. 1994).

Tortoises are known to take lengthy forays from their home range and return. Tortoises commonly travel 470-823 meters per day and males occasionally cover 1000 meters per day (Berry 1986). Shown in Figure 5 is a sample of travel distances over 1-6 days for a group of marked males and females south of the Desert Tortoise Conservation Center in California. Given these data it seems likely that approximately 5% of female tortoises might cross into an adjacent population within a year.

In the model, the following assumptions were made about dispersal among populations. In the fragmented metapopulation, tortoises did not cross the roads, i.e., no dispersal was allowed across the highways shown in Figure 3. Within a year, a maximum of 5% of a population could migrate equally into the neighboring populations. For example, in the unfragmented metapopulation, based on these assumptions, the tortoises in the population one could travel to either population two or four. In the fragmented metapopulation, tortoises in populations seven and eight were completely isolated from all other populations by roads but tortoises could travel from population six to population ten and vice versa.

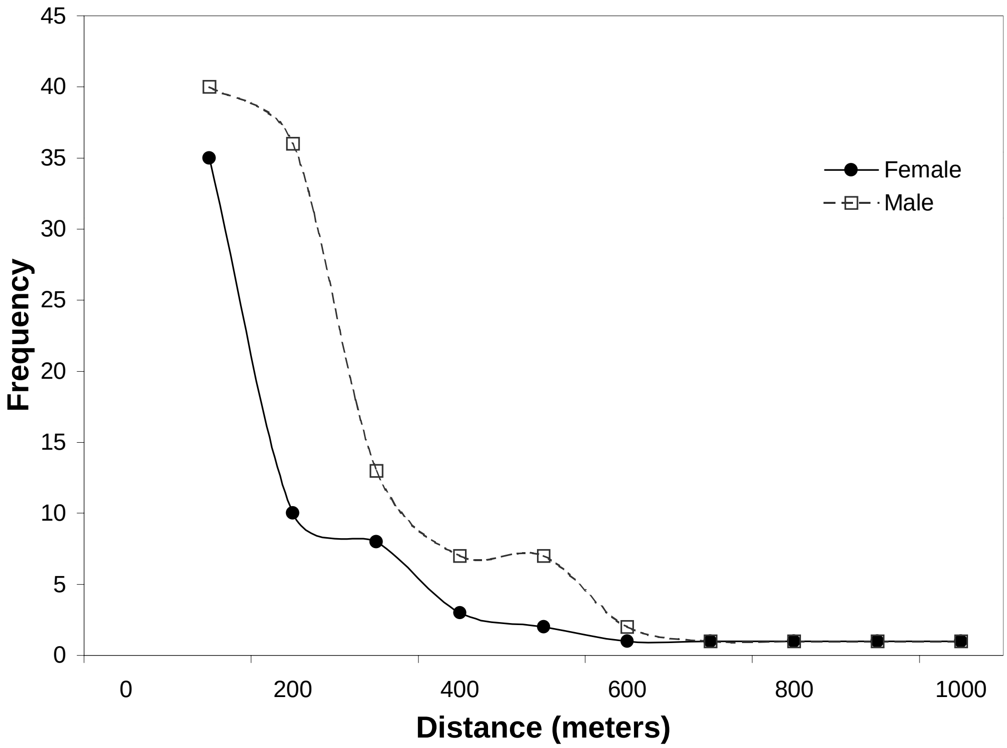


Figure 5. Frequency of dispersal (in meters) for male and female desert tortoises based on mark-recapture studies (O'Connor et al. 1994).

Density Dependence

Little is known about density dependence in desert tortoise populations. Tortoises use burrows and do defend them, which indicates a degree of territoriality. As a cautious approach to density dependence in the absence of data, the model includes a density ceiling or carrying capacity (K) which was assumed to be the maximum observed density in field studies, Tables 4 and 5. The implementation of a density ceiling in the model means that the demographic rates are used as is for the entire 100 years regardless of the number of individuals, i.e., declining populations remain declining throughout the simulation. This type of density dependence assumes that populations do not compensate for low population abundance with increased reproduction.

As a less pessimistic alternative, simulations were run with scramble competition for populations with fecundities greater than zero and with the ceiling described above for the remaining (severely declining) populations. The carrying capacity (K) was specified for all populations as described above and the maximum population growth rate (R_{max}) was either 1.025 or 1.05 (i.e., an average annual increase of 2.5 or 5%). The R_{max} describes the increase or recovery potential of a population from low density; it is the largest population growth rate expected under very low population densities. There were no data on the R_{max} for the desert tortoise populations west of the Colorado River so we assumed either 1.025 or 1.05 for R_{max} in the model. Scramble (also known as Ricker) competition would mimic the effects of a limiting resource such as food (Akçakaya 1997). This type of density dependence is implemented in RAMAS to inflate survival and/or fecundity values when population densities are low, so that the population grows at the rate determined by the density dependence function. Scramble competition or a similar type of density dependence is plausible for this species since desert tortoise females are capable of substantial annual reproduction (1-14 eggs per clutch and 0-3 clutches per year for each female).

Populations

Using mark-recaptured data from 1977-1989 on BLM plots, the average annual growth rate for some of the populations was calculated as the geometric mean of the density estimate. For those populations, which did not include a BLM plot, the population was assumed to have a growth rate of 1.020 per year, or that they were stationary (neither increasing nor decreasing in abundance). An annual growth rate of 1.02 per year produces a stationary population with normal variance in survival and fecundity.

In the model, the demographic rates for each region were adjusted by modifying the egg counts (Table 3) by a factor to reflect the population growth rates, Tables 4 and 5. This factor included the probability of surviving the first year of life, but it also included an adjustment so that the demographic matrix produces the average population growth rate assigned. The clutch data included in this model were from a limited number of years that also occurred during a drought; they are likely to be an underestimate of the true long-term average number of daughters produced per female. For these reasons, factors larger than one were plausible. For example, to produce a growth rate of 1.02, the 3.07 daughters per female for size class 5 was multiplied by the survival factor of 1.580 for a final fecundity value of 4.842 one-year olds produced annually. The factor and the resulting fecundities for each growth rate are shown in Table 6.

Table 6. The annual fecundity values for each age class based on the average number of eggs per female, *e*, multiplied by the survival factor, *F*, to produce the appropriate average annual growth rate.

		Fecundity		
Growth Rate	**Factor**	**Class 4**	**Class 5**	**Class 6**
1.020	1.580	4.842	6.768	9.875
1.009	1.300	3.984	5.568	8.125
0.972	0.622	1.912	2.673	3.900
0.943	0.304	0.932	1.302	1.900
0.916	0.132	0.405	0.565	0.825
0.914	0.126	0.386	0.540	0.788
0.843	0.000	0.000	0.000	0.000
0.833	0.000	0.000	0.000	0.000

Model Structure

The model was a female-only, eight-stage, length-based stochastic model with eight or 26 populations, environmental stochasticity, and ceiling-type density dependence. Dispersal for each population was 5% annually divided evenly among immediately adjacent populations in the unfragmented scenario (Figure 2) or among the available adjacent populations not separated by a major road in the fragmented scenario (Figure 3).

In this stage-based model, the diagonal element of the transition matrix described the proportion of tortoises in one stage that survives and remains in the same stage the next year. This was equal to the survival (s) rate multiplied by one minus the growth rates (1-g). A subdiagonal element described the proportion of tortoises that survived, and grew to the next size class (stage) by the next year. This was equal to the survival rate multiplied by the growth rate for each stage. We assumed, in the absence of data, that the values for stage 1 ("yearlings" or one-year olds) were the same as those estimated for stage 2 (smaller than 60 mm carapace length; Doak et al. 1994). Fecundities, the first row of the matrix, were the products of the average number of eggs/female/year (e) and the factor (F) for the appropriate growth rate (as described above in the fecundity section). Table 7 shows a typical matrix structure.

Table 7. The transition matrix for the desert tortoise population model where *s* is survival rate, *g* is growth rate, *e* is egg count for that stage and *F* is the survival factor dependent of the assigned growth trend category.

	0	1	2	3	4	5	6	7
0						e_5*F	e_6*F	e_7*F
1	s_2	$s_2*(1-g_2)$						
2		s_2*g_2	$s_2*(1-g_2)$					
3			s_2*g_2	$s_3*(1-g_3)$				
4				s_3*g_3	$s_4*(1-g_4)$			
5					s_4*g_4	$s_5*(1-g_5)$		
6						s_5*g_5	$s_6*(1-g_6)$	
7							s_6*g_6	s_7

Annual Variability

The year-to-year variability of the demographic rates in the transition matrix was estimated in the following manner. The standard deviations for s and g were calculated from the Goffs data shown in Tables 1 and 2. These data, though, included both spatial and temporal variability in the survival rates. Only the temporal variation or year-to-year variation in the annual survival rates should be included in the model. Since the spatial data indicated that there would be a large amount of variability among populations, we assumed that only half of the measured variation (standard deviation) was temporal. Therefore, we used half of the measured values shown in Tables 1 and 2 for the standard deviation of *s* and *g*. The standard deviation of (1-*g*) was the same as that for *g*. For the subdiagonal elements, the standard deviation of the product of *s* and *g* was estimated as the square root of the variance of the product (Kendall and Stuart 1958):

$$var_{(a \bullet b)} = var_a \bullet (mean_b)^2 + var_b \bullet (mean_a)^2 + [2 \bullet mean_a \bullet mean_b \bullet (corr_{ab} \bullet sd_a \bullet sd_b)],$$

where *a* is *g* and b is *s*, *var* is variance, *sd* is standard deviation and *corr* is the correlation between *g* and *s* which was assumed to be zero. We assumed zero for the correlation between survival and growth because Doak et al. (1994) reported a mix of positive and negative correlations. For the diagonal elements, the above relationship was used substituting (1-*g*) for *a* instead of *g*.

To estimate the annual variability of fecundity, another assumption was required. We assumed that the coefficient of variation (standard deviation/mean) for *e* was the same as for the final fecundity value *f*. The standard deviation for the number of eggs, e, was estimated from the Goffs data as shown in Table 2. Therefore, the standard deviation for the product e•F was equal to the product of coefficient of $\text{variation}_e \bullet \text{mean}_e \bullet F$.

Transmission Line Siting

We examined a number of different potential line configurations to evaluate the potential effects that additional transmission lines would have on the currently fragmented tortoise metapopulation. Luke et al. (1991) estimated that for each mile of transmission line 0.16-0.24 mi^2 would be impacted, and, by the year 2000, an additional 675mi^2 would be impacted by 15 new transmission lines. Using this estimate, construction of the transmission corridor and subsequent maintenance would render 116.5km^2 of habitat unsuitable for the desert tortoise for each transmission line constructed. Assuming that a single line running through a population eliminated 116.5km^2 of suitable habitat, the potential effects of the new transmission lines can be modeled as a reduction in the carrying capacity of the affected population. We examined four possible siting scenarios: one line passing through each of the five largest populations, one line passing through each of the five smallest populations, one line passing through each of the fifteen smallest populations, and one line passing through each of the twenty six populations. In each affected population, we reduced the carrying capacity by 116.5km^2 while keeping all other parameters the same as in the previous models.

Effect of Raven Predation

Potential destruction of habitat is a direct effect that may be caused by a transmission corridor. A potential indirect effect is an increase in the number of predators locally. Knight and Kawashima (1993) and Knight et al. (1995) demonstrated that a tortoise predator, the common raven, is present in higher densities along power lines than in desert habitat with no utility structures. Ravens are also found in higher densities along major roads compared to secondary roads (Austin 1971). Ravens are thought to be significant predators on desert tortoises based on indirect evidence. Juvenile shells have been found under raven nests and perching sites and forensic analysis of juvenile shells suggests an avian predator; concomitantly, there has been a decrease in the density of juveniles on BLM study plots (Luke et al. 1991).

In the metapopulation model, the impact of additional mortality on juveniles was incorporated to assess the impact an increasing number of ravens might have on specific tortoise populations. Since there are no direct data that indicate the actual rate of predation, we assumed that ravens would increase the mortality of the classes 0-2 (less than 100mm in carapace length) either 10% or 20% annually in an affected population. For these predation scenarios, we assumed that only the youngest three classes were affected and that no habitat was lost. It is important to remember that this was additional mortality, since inherent in the demographic parameters already was the existing level of predation on tortoises. Therefore, these models represented the effects of increasing the amount of predation on the populations.

Approach

The analysis of the metapopulation dynamics with the model described above consisted of a series of simulations. Each simulation had 10,000 replications, and each replication projected the abundance of each population for 100 time steps (years). At each time step, the number of individuals in each age class at each population was estimated using survival rates and fecundities sampled from random (lognormal) distributions with the means and standard deviations as described above.
The resulting graphs show risk of decline (within the simulated time horizon) as a function of amount of decline. The risk of decline was calculated as the proportion of replicates that decline by a given amount (from the initial abundance) by the end of the simulated time period, and are reported as a function of percent decline from the initial total abundance (Akçakaya 1992). Statistical significance was estimated using the Komogorov-Smirnov test (Sokal and Rohlf 1981) for the maximum vertical distance between two terminal percent decline curves. Note, that this test is based on continuous distributions and the results are considered statistically conservative (Akçakaya 1997). We compared the long-term viability with and without dispersal among populations and with different types of density dependence.

Assumptions

As in any model of metapopulation dynamics, the model of the desert tortoise makes a number of assumptions. These assumptions were necessary largely because of data limitations, but also to keep the model simple enough to be reasonably functional. Most of the assumptions were stated in the description of each parameter in the previous sections. Below we list the major assumptions of the model.

(1) Either eight (unfragmented scenario) or twenty-six (fragmented scenario) populations function as discrete populations loosely connected through migration, forming a metapopulation.
(2) The average annual survival rates were estimated from the long-term Goffs data set.
(3) The initial abundance for each population was estimated from BLM plot density estimates (Luke et. al. 1991) and the Desert Tortoise Recovery Plan density estimates (Desert Tortoise Recovery Plan 1994) and divided in half (assuming only females and a 1:1 sex ratio in the model).
(4) The density within a population was assumed uniform throughout the entire area encompassed and only habitat suitable (based on the G.I.S. analysis) for the tortoise

was included in estimations of population area, tortoise density and carrying capacity.

(5) The average growth rate for populations without BLM data was set so that the median population size (of all trajectories) would neither decline nor increase under baseline parameters. This corresponded to a growth rate of about 1.02.

(6) For the declining populations, the average growth rate of the population was set so that the median population size (of all trajectories) would decline at the rate estimated from the BLM plot field data.

(7) Density dependence was modeled as a ceiling that corresponded to the maximum of the BLM plot density estimate and the DWMA density estimate for that population.

(8) For some simulations, scramble competition was imposed on the populations with nonzero fecundities with a maximum growth rate of either 2.5 or 5% annually.

(9) Reproduction began at stage 5, i.e., carapace length of 180-207mm.

(10) Fecundities were the product of number of eggs per female for that stage (based on the clutch data for Goffs from 1983-1985) and a factor that represented the survival of offspring to one year (the result of fixing the growth rate at about 1.02 or the assigned declining rate with the assigned survival rates).

(11) The standard deviations of annual survival rates were assumed to be 50% of the standard deviation from the Goffs data (Doak et al. 1994).

(12) The standard deviation for fecundity was estimated from the Goffs clutch data (1983-1985) assuming that the coefficient of variation for the survival factor was the same as that for the stage-specific egg count per female.

(13) No dispersal was allowed across major roads or highways in the fragmented scenario.

(14) A total of 5% of a population would annually disperse equally into its nearest available neighbors.

Results

In general, a large decline (42-81% decline) in the mean number of tortoises occurred over the 100 years of the simulation regardless of the level of fragmentation. This resulted primarily from the extinction of populations that had growth rates lower than one in the fragmented scenario. Of the twenty-six populations, half (29.3% of the total metapopulation abundance) are declining in size because of their population growth rates. Table 8 lists the number, the abundance and the carrying capacity of populations that were stable, declining or severely declining (i.e., population growth rate less than 0.9).

Table 8. The number, initial abundance and carrying capacity of tortoise populations which were classified as stable, declining or severely declining.

Growth Rate	Number	Initial Abundance	% of Total	Carrying Capacity
Stable	13	3,851,176	70.7	4,414,949
Declining	11	1,354,500	24.9	4,121,953
Severely Declining	2	239,338	4.4	328,285

For the metapopulation with ceiling density dependence on all populations, the risk of declining in abundance in the next 100 years was quite large. The probability that there would be a 50% decline from initial abundance in the tortoise metapopulation by the end of 100 years was 86% under these density dependent conditions with no fragmentation and 100% with fragmentation. The probability of a large decline (80% of initial abundance) is 45% or 71%, without or with fragmentation, respectively. The chances of a 100% decline from initial abundance for the metapopulation, though was zero.

Alternatively, if scramble competition was imposed on the stable populations, the risk of declining in abundance by the end of 100 years was reduced. With no fragmentation, under scramble competition with a R_{max} of 1.025 (2.5% annual increase), the probability of an 80% decline dropped to 44% compared to 45% with a ceiling. When the R_{max} was increased to 1.05 (5% annual increase), the risk of declining 80% from initial abundance fell to 8%. With fragmentation, there was also a decline in the risk for models with scramble competition compared to a ceiling; the risk of a large decline dropped to 33% from 71% or to 0% from 71% with R_{max} of 2.5 or 5%, respectively. Table 9 compares the risk of a 50%, 80% and 100% decline from initial abundance for the metapopulation when the stable populations have a ceiling or scramble competition for the fragmented and unfragmented scenarios. Figure 6 illustrates the terminal risk of decline for the unfragmented metapopulation with a ceiling or scramble competition. Figure 7 illustrates the terminal risk of decline for the fragmented metapopulation.

Table 9. The terminal risk for the tortoise metapopulation of declining from initial abundance 50%, 80% or 100%, under various density dependence types with and without dispersal, for the unfragmented scenario and the fragmented scenario.

			Terminal Risk of Decline		
	R_{max}	**Dispersal**	**50%**	**80%**	**100%**
Unfragmented Scenario					
Ceiling		no	0.86	0.45	0
Ceiling		yes	0.96	0.66	0
Scramble	2.5%	no	0.84	0.44	0
Scramble	2.5%	yes	0.91	0.47	0
Scramble	5%	no	0.56	0.08	0
Scramble	5%	yes	0.64	0.10	0
Fragmented Scenario					
Ceiling		no	1.00	0.71	0
Ceiling		yes	1.00	0.77	0
Scramble	2.5%	no	0.93	0.33	0
Scramble	2.5%	yes	0.88	0.15	0
Scramble	5%	no	0.46	0.00	0
Scramble	5%	yes	0.36	0.00	0

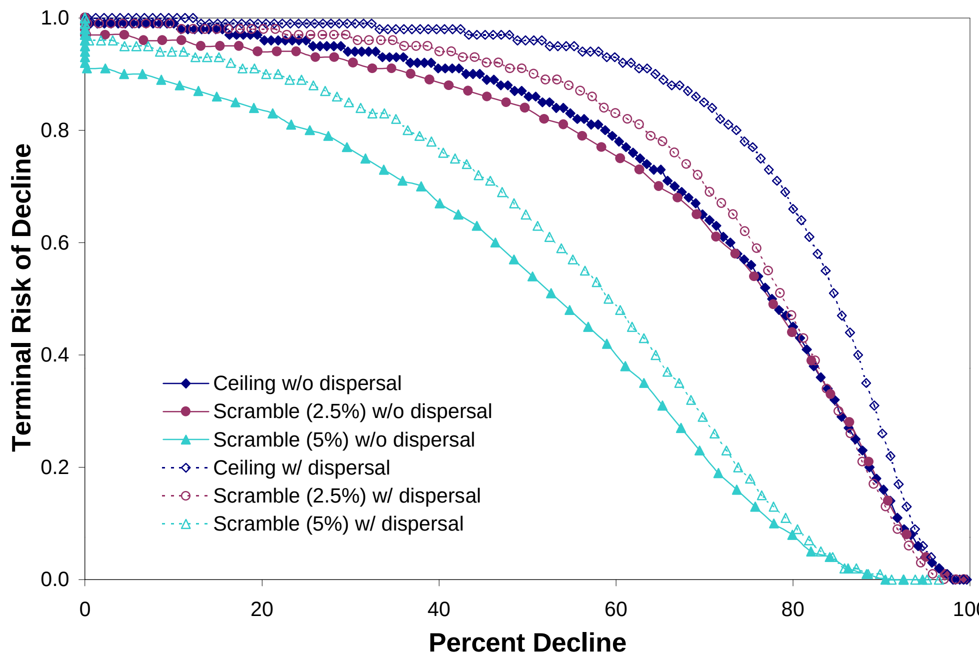


Figure 6. The risk of a decline in abundance for the unfragmented metapopulation with a ceiling or scramble competition, with and without dispersal.

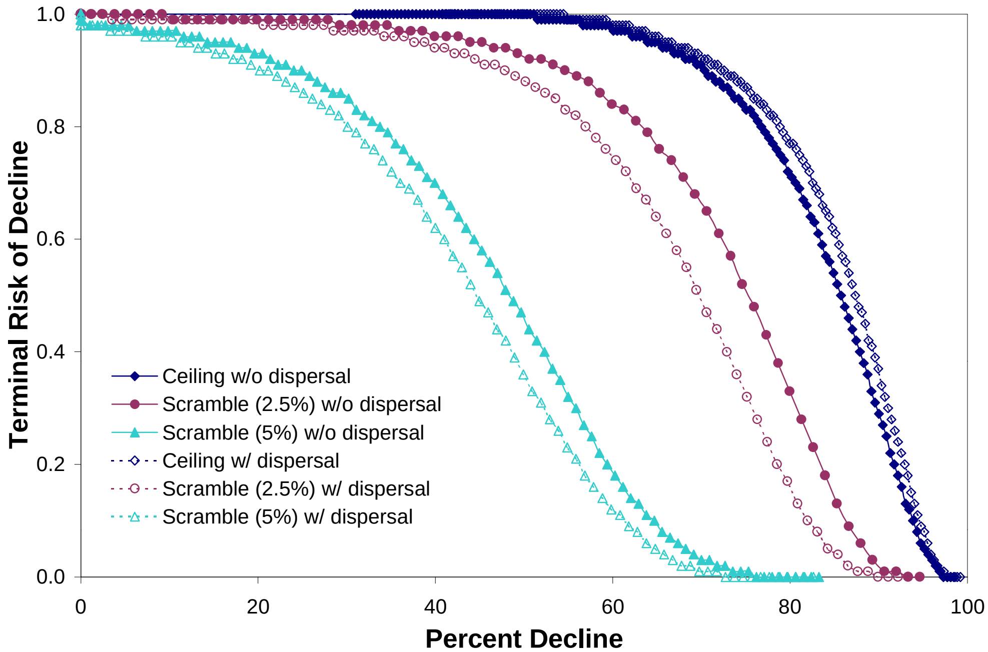


Figure 7. The risk of a decline in abundance for the fragmented metapopulation with a ceiling or scramble competition, with and without dispersal.

Fragmentation increased the risk of a decline and decreased the final metapopulation abundance under either a density ceiling or scramble competition. Under scramble competition and dispersal, there was a maximum increase of 31-37% in the terminal risk of a decline in abundance (significant at the 0.001 level in the Kolmogorov-Smirnov test; Sokal and Rohlf 1981). A similarly statistically significant but smaller (12%) maximum increase in the risk of decline occurred under a density ceiling with fragmentation.

The effect of dispersal was dependent on the assumptions of density dependence and whether or not there was fragmentation. For either the fragmented or unfragmented metapopulations, the presence of dispersal increased the risk of a decline in abundance. For the populations with scramble competition, dispersal increased the risk of decline with no fragmentation and decreased the risk with fragmentation. Note, though, that doubling the maximum annual population growth rate (to 5 from 2.5) did not consistently halve the risk of a decline.

Effects of Habitat Loss

The potential effect of transmission line siting was simulated in the metapopulation models as a reduction in the carrying capacity, i.e., the reduction of suitable available habitat. Given the assumption that an affected population had the addition of a single transmission line, the risk of a decline in abundance remained the same or increased slightly with the loss of habitat. Under a density ceiling, the probability of a 50% decline remained 100% but the probability of a larger (80%) decline increased to 79-80% compared to 77% with no habitat loss. In the case of the metapopulation regulated by scramble competition, the probability of a 50% decline increased from 36% to 37-52% compared to scenarios with no habitat loss, although the probability of a large decline in abundance remained zero.

There was an increase in the risk of decline when the smaller populations (as compared to the larger populations) were affected by the siting of new transmission lines increased; this trend was more noticeable under scramble competition. Figure 8 compares the terminal risk of a decline in abundance for the four siting scenarios: (1) only 5 largest affected; (2) only 15 smallest affected; (3) only 5 smallest affected; (4) all populations affected. Table 10 compares the risks for a 50%, 80% or 100% decline in abundance for the line siting scenarios.

The greatest risk of a decline under scramble competition was found when only the five smallest populations were affected (52% compared to 36% with no additional transmission lines). The addition of transmission lines in the smallest populations significantly increased maximum difference in the risk of a decline by 10-18% ($p=0.05$; Kolmogorov-Smirnov test). The smallest maximum increase in the risk of a decline occurred under scramble competition occurred when only the five largest populations were affected (37% compared to 36% with no additional transmission lines). The addition of transmission lines to the largest or all of the populations also produced a statistically significant ($p=0.05$) but slight maximum increase of 2% in the risk of a decline.

Table 10. Terminal risk of declining in abundance for the fragmented metapopulation under different transmission line siting assumptions.

			Terminal Risk of Decline		
	R_{max}	Dispersal	50%	80%	100%
Line Scenario 1: Single line through each of 5 largest populations					
Ceiling		yes	1.00	0.79	0
Scramble	5%	yes	0.37	0.00	0
Line Scenario 2: Single line through each of 15 smallest populations					
Ceiling		yes	1.00	0.79	0
Scramble	5%	yes	0.47	0.00	0
Line Scenario 3: Single line through each of 5 smallest populations					
Ceiling		yes	1.00	0.80	0
Scramble	5%	yes	0.52	0.00	0
Line Scenario 4: Single line through each population					
Ceiling		yes	1.00	0.79	0
Scramble	5%	yes	0.39	0.00	0

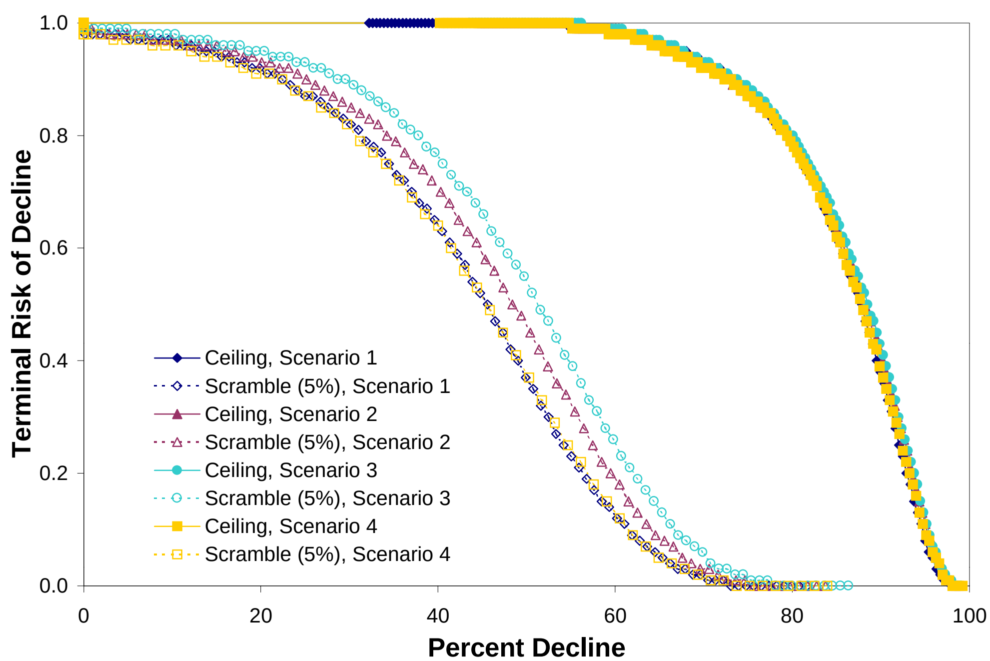


Figure 8. A comparison of the risk of a decline in abundance for the fragmented metapopulation with different transmission line siting scenarios.

Habitat loss, in general, reduced the metapopulation abundance and increased the risk of a decline even under the assumption of scramble competition with a maximum growth rate of 1.05. As Figure 9 illustrates the risk of a 50% decline in abundance increased from 36% with no habitat loss to 42, 48, 64 or 78% with a 5%, 10%, 20%, or 30% loss of habitat respectively. The maximum increase in the risk of a decline with 5-30% habitat loss compared to no habitat loss was significant (p=0.001; Kolmogorov-Smirnov test).

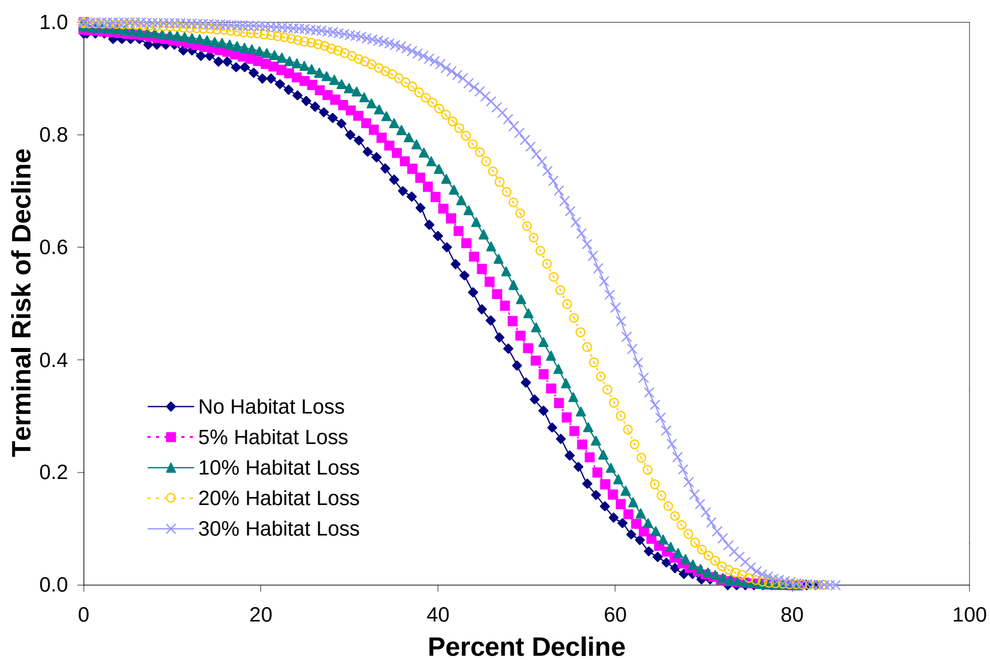
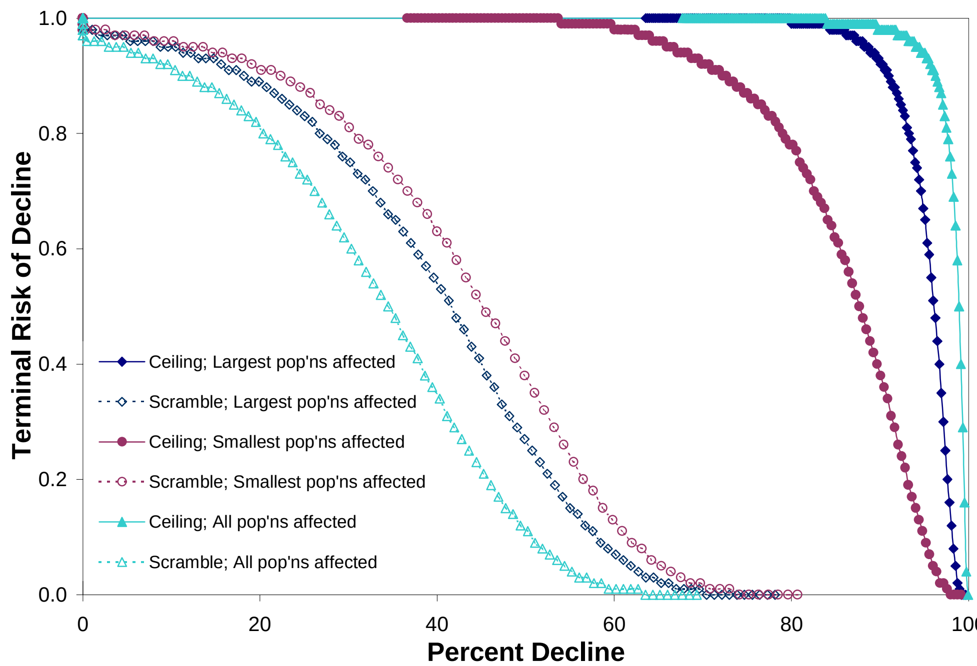


Figure 9. Comparison of the risk of a decline in abundance with increasing amounts of habitat loss under scramble competition (Rmax=1.05) and with dispersal among populations in the fragmented metapopulation.

Effects of Raven Predation

The effects of increased predation by raven predators were simulated in the models as a reduction of 10% or 20% in the survival of the smallest individuals (carapace length <100mm). A 20% reduction in survival reduced had a larger effect than a 10% reduction in survival. Unlike habitat fragmentation, 10 or 20% reduction in the survival of the youngest individuals only slightly, i.e., 2-3% ($p=0.05$), increased the maximum difference in the risk of a decline when predation was applied to only the smallest populations. The statistically significant maximum increase in the risk was greater when predation was applied to only the largest populations, 10-22%, or when all of the populations were affected, 29-54% ($p=0.01$) under scramble competition. In all cases the

(a) 10% Raven Predation



(b) 20% Raven Predation

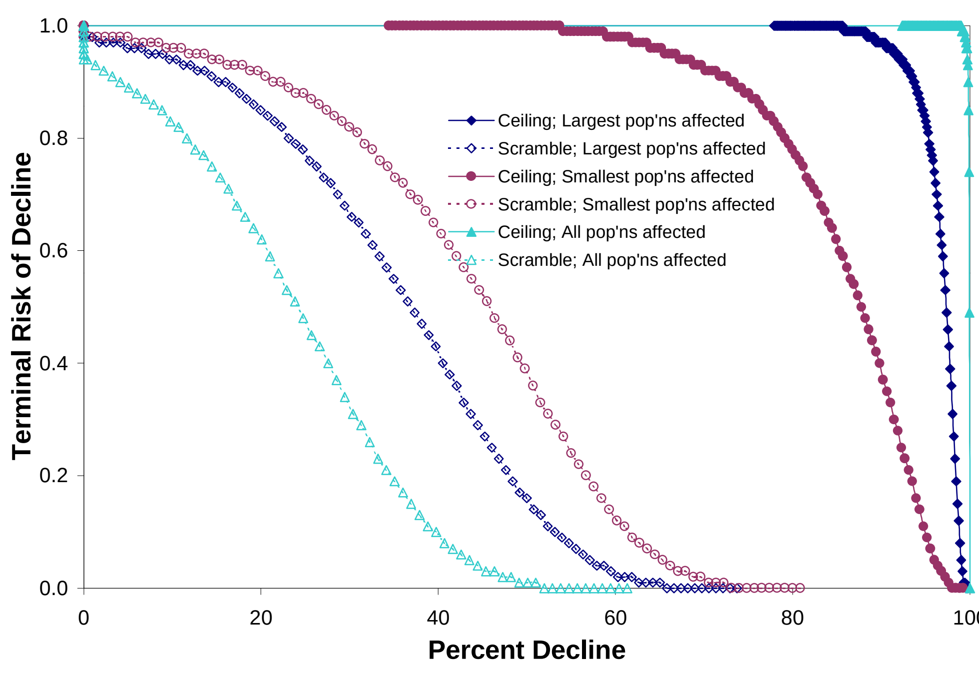


Figure 10. A comparison of the risk of a decline in abundance for the fragmented metapopulation with different raven predation scenarios and (a) 10 or (b) 20% predation.

probability of a decline larger than 70% in abundance was zero under scramble competition with dispersal. Interestingly, though, the final mean metapopulation abundance was larger with predation than without predation under scramble competition with dispersal.

Similar trends occurred under ceiling type density dependence. The maximum increase in risk was much larger for scenarios with predation: 62-75% if only the largest populations were affected; 2-3% if only the smallest populations were affected; and 87-99% when all populations were affected by predation (p=0.01). The risk of a large (>70%) reduction in abundance was significantly greater with predation under a density ceiling. Unlike under scramble competition, though, the final mean metapopulation abundance was smaller with predation than without predation under a density ceiling.

Discussion and Conclusions

The desert tortoise is a slow-growing, long-lived, species with specific habitat requirements. Human recreation, development, transportation, military activities, energy transmission and mineral extraction have steadily encroached upon the desert habitat. Mounting evidence suggests that the desert tortoise populations are declining throughout the region due to these and many other human influences. Luke et al. (1991) estimated that 15% of desert tortoise habitat was eliminated between 1980 and 1988. As of 1984, 41% of the land that supports high densities of desert tortoises was leased or partially leased for oil and gas exploration and extraction (Luke et al. 1991). One estimate (Luke et al. 1991) suggested that 1204 mi^2 were impacted by heavy off-road vehicles used for military maneuvers in the desert. The desert tortoise distribution west of the Colorado has been fragmented into populations that are further subdivided by the lethal barriers of roads and highways.

There is little known about density dependence and the maximum growth rate that is likely under optimal conditions for the desert tortoise. Assuming exponential growth at the growth rate measured in the BLM field studies may underestimate the compensation possible for these tortoise populations. The introduction of scramble competition with a R_{max} greater than one more closely simulates this potential compensatory effect. The resulting risks of decline under these scenarios are reduced compared to the exponential scenario.

We chose to compare the more pessimistic assumption of a density ceiling with that of scramble competition with a maximum allowable population growth rate of 2.5 or 5%. The assumption of scramble competition results in populations that increase at a faster rate (close to R_{max}) when below the carrying capacity than when near the habitat limits. In scenarios with a density ceiling, populations increased or decreased based on the current demographic parameters as measured in field studies regardless of the number of individuals in a population. Half of the populations, therefore, under the density ceiling were declining, increasing the overall risk of a metapopulation decline regardless of the other parameters. Comparison of these two different assumptions provides an estimate of what the smallest versus the largest impacts are likely to be based on available data.

In general, there is a moderate risk of a 50% decline in the metapopulation abundance by the end of 100 years assuming the current demographic trends continue, especially for the fragmented metapopulation. Even under the more optimistic assumption of scramble competition, the risks of a 50% decline are ≥36%. The high degree of fragmentation has a large influence on the long-term viability of the species. As this analysis suggests, populations that are declining and separated from other populations by roads, are not likely to persist for the next 100 years under conditions similar to the present. Declining populations that are within dispersal distance of another population siphon off individuals, i.e., act as a "sink" population, from nearby ("source") populations, increasing the decline for the metapopulation. Fragmentation lessens this effect somewhat when scramble competition is assumed but only at the higher growth rate of 5%, otherwise the risk of 50% decline is greater with fragmentation compared to the unfragmented metapopulation.

For the evaluation of impacts of transmission line sitings, we assumed either: (1) habitat is being lost or (2) raven predation increases. The model's results suggest that location of the impact determine the magnitude of the increase in risk either of these factors may have on the metapopulation. The greatest impact for habitat loss is found occurs habitat loss only affects the smallest populations, and the greatest impact for raven predation occurs when predation is applied to only the largest populations. Our assumption that a fixed amount of habitat was lost for each transmission line added produced a risk of a decline similar to an overall loss of 5% of the habitat. Larger losses of habitat produced significantly greater risks of a metapopulation abundance decline.

The effects of raven predation were quite large under the pessimistic assumption of a density ceiling. Interestingly, though, the risks with 10 or 20% predation were similar or slightly less than without predation when scramble competition was assumed. The mitigation of the predation effects is probably due to the compensatory increase in reproduction, under scramble competition, as the affected populations are reduced further below their carrying capacities. We caution that this compensatory effect would be less if the actual R_{max} was less than the 5% assumed and does not exist under the assumption of a density ceiling.

The model makes a number of predictions. Fragmentation, habitat loss (reduction in carrying capacity) and raven predation increased the risk of a decline in abundance for the tortoise metapopulation. The magnitude of the increase in risk from these factors was dependent on (1) the magnitude of the impact (e.g., 10% versus 20% predation), (2) which populations are affected by the impact (e.g., large versus small populations), and (3) the assumptions about density dependence. Our research predicted that the magnitude of potential impacts of transmission line siting and maintenance was dependent on which populations were affected, but the effects were usually moderate.

It is important to remember, though, that the baseline risk of a 50% decline in the metapopulation abundance was quite high with no additional impacts except under the most optimistic density dependence assumptions. This finding supports empirical studies indicating that these populations are experiencing a large decline in abundance and are probably vulnerable to some extent to any additional disturbance. The model and the results would be strengthened, therefore, by additional data on density dependence in natural populations such as carrying capacity and maximum growth rate and on the effects of raven predation.

This research suggests that additional empirical studies of the tortoise warranted, especially in the area of density dependence and predation. Given the assumptions in the model, though, the potential impact of a new transmission line may be estimated with this technique given the specific location and extent of the line and compared with alternative plans. As this analysis has shown, ecological risk assessment is a valuable management tool that allows comparison of alternatives even with limited data and highlights future research needs. Specifically, this example clearly shows the importance of understanding spatially-explicit metapopulation dynamics when evaluating management alternatives.

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Appendix VII

The Metapopulation Model as an Educational Tool: Providing Internet Access to RAMAS® GIS Demonstration Software

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APPLIED
BIOMATHEMATICS®

The metapopulation model as an education tool: Providing Internet access to RAMAS GIS demonstration software

Background and objectives

In this project we developed a version of RAMAS that can be downloaded from the World Wide Web (WWW), which allows users to run metapopulation models based on the real world examples of the Desert Tortoise and the California Gnatcatcher. These models serve as an excellent educational tool. By placing a version of the metapopulation model on the World Wide Web, members of the public may test the alternatives for themselves. Users can pose a question, examine the modeling predictions, and draw their own conclusions.

Methods

The program RAMAS GIS was modified and compressed to be readily downloadable off of the internet. Sample data files that include the necessary demographic and spatial elements for use in RAMAS GIS were created for the Desert Tortoise and the California Gnatcatcher metapopulation models. Additional files that illustrate example results were also generated for use in the program. A web site was created on the World Wide Web (WWW), that hosts the demo version of RAMAS GIS (http://www.ramas.com/demo/tortoise/index.htm) and the additional sample files, data, support documents and general guidance on the use of the program and how to interpret the results. Included on the site are the background materials, description of data utilized and an interactive version of the metapopulation model. The web site provides important information for potential users of RAMAS GIS. This includes guidance on the use of the program and on the interpretation of the risk results of the program. These documents are in a format that is suitable for the web and can be downloaded for the user's convenience. Additional information is provided on the specific examples that are available for use in the program.

Results

These html files are in a folder called "webdemo" or can be viewed in their . temporary home on the web (http://www.ramas.com/demo/tortoise/index.htm).
There are three sections to the web site:

- Part 1: Conservation and Management of Coastal Sage Scrub
  - a. project description and sample file tutorial (accessed via file: *gnat.htm*)
  - b. sample model files (*gnatmdls.zip*) that compare three hypothetical management strategies
- Part 2: Desert Tortoise Metapopulation Dynamics (Phase II)
  - a. project description in the form of a slide show (accessed via file: *title.htm*)
  - b. sample model files (*tortmdls.zip*) that examine seven different parameter sets
- Part 3: The metapopulation model as an educational tool
  - a. demo program available (*rgdemo.exe*)
  - b. help files in Acrobat form (*readme.pdf*) or as a text file (*readme.txt*)

c. two additional sets of models (*gnatmdls.zip* and *tortmdls.zip*)

Summary

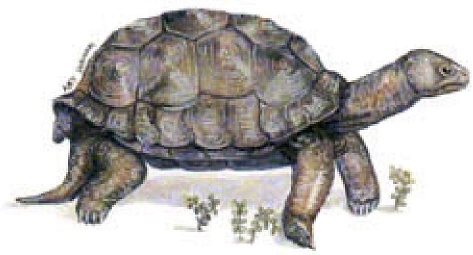
In this project we developed a version of RAMAS that can be downloaded from the World Wide Web (WWW), which allows users to run metapopulation models based on the real world examples of the Desert Tortoise and the California Gnatcatcher. The full commercial version of RAMAS GIS is available from Applied Biomathematics (www.ramas.com) as well as other useful software packages as shown in Table 1. These models serve as an excellent educational tool. By placing a version of the metapopulation model on the World Wide Web, members of the public may test the alternatives for themselves. In addition, the models serve as a vehicle to demonstrate Southern California Edison's and EPRI's commitment to environmental issues and their research efforts. Users can pose a question, examine the modeling predictions, and draw their own conclusions. Students will have the opportunity to learn about the methods and tools used for Population Viability Analysis and risk assessment. Not only does this demonstrate the efficacy of the technique used but it allows a broader public participation in important regional issues.

Table 1. A price list for a single user license for some of the ecological risk assessment software available from Applied Biomathematics (www.ramas.com). Site licenses or multiuser licenses are also available.

	Single User License		
	College & University	**Government & Non-profit**	**Other**
RAMAS Red List	295	295	495
RAMAS GIS	995	1,595	1,895
RAMAS Metapop	395	595	795
RAMAS Stage	295	495	625
RAMAS Age	295	495	625
RAMAS Ecotoxicology	395	595	795
RAMAS Risk Calc	345	525	695

Ecological Risk Assessment for Endangered Species

These projects by Applied Biomathematics examine the long-term population dynamics of an endangered reptile species in the Mojave Desert and of a threatened bird species in southern California. This work has been generously supported by funding through Southern California Edison and Electric Power Research Institute.

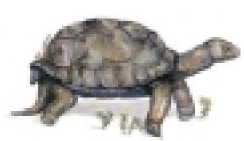


IMPACTS ON ENDANGERED SPECIES

How do we protect native species while serving public needs for recreation and power generation?

- *Ecological risk methods allow you to assess the impacts of alternative management strategies on the populations of endangered species.*
- *We can assess how anthropogenic impacts affect future population abundance, i.e., risks of population decline, using population modeling.*
- *We can also use models to design management strategies to foster native species and assess the tradeoffs with other goals.*

Two example projects:



Desert Tortoise

California Gnatcatcher

Click here to see a slide show or Click here to see protect details the model. or the model.

Ecological Risk Analysis for the California Gnatcatcher

Contents:

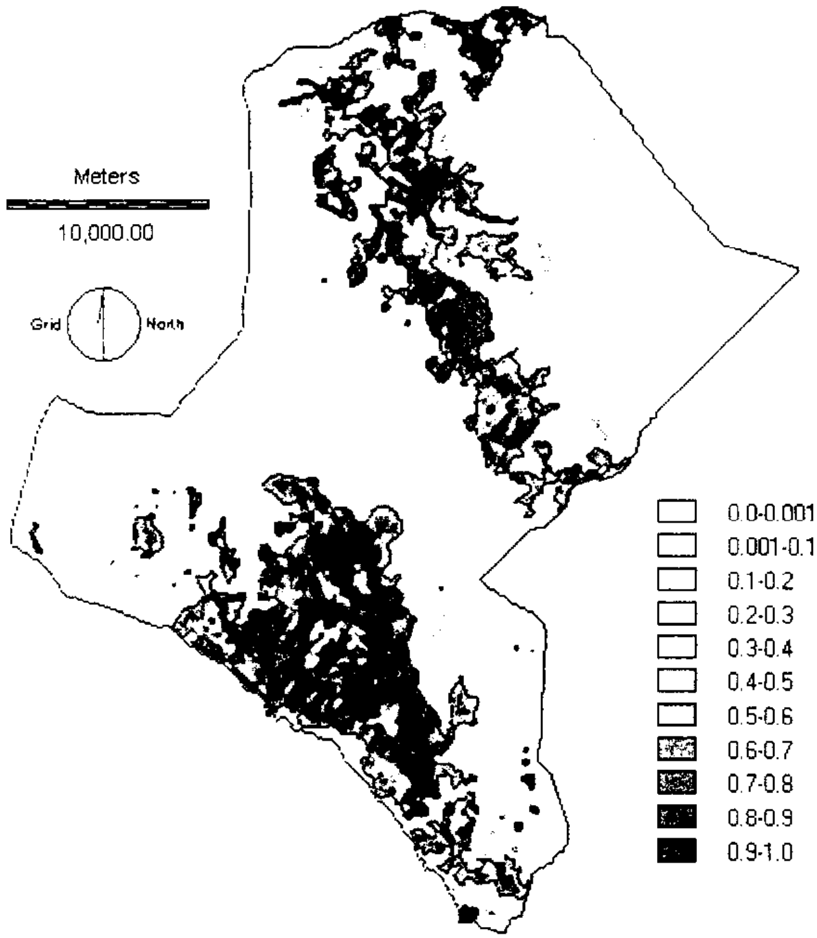
Project Summary

The California Gnatcatcher is a federally threatened subspecies inhabiting the coastal sage scrub community in southern California. The coastal sage scrub is a distinctive plant community that has declined due to extensive agricultural and urban development in this area. Our project involved an analysis of the dynamics of the California Gnatcatcher in central and coastal Orange County, California. For this analysis, we first developed and validated a habitat model for the species, using GIS data. We then used this habitat model as a basis of a metapopulation model, which included demographic data such as fecundity, survival, as well as variability in these demographic rates.

Habitat Modeling

- We used GIS data (raster maps exported from ARC/INFO) on the vegetation and topography of an approximately 850 km^2 region of Orange County, California.
- Using these data and the locations of gnatcatcher pair observations, we estimated a habitat model with logistic regression.
- Significant variables included percentage of coastal sage scrub, elevation, distance from grasslands, and distance from "trees" (forest, woodland, chapparal), and various interactions among these variables.
- We validated the model by estimating the habitat function using only data on gnatcatcher locations in the northern half of the study area, and predicting the habitat suitability of the locations where gnatcatcher pairs were observed in the southern half.
- We entered the habitat model in RAMAS GIS to create a habitat suitability map

(see Figure at right).



Habitat suitability map for the California Gnatcatcher in Orange County, CA. Darker red indicates more suitable habitat; white indicates unsuitable habitat. The black lines show the borders of habitat patches identified by RAMAS GIS. For details, see REFERENCE.

Metapopulation Modeling

MODEL

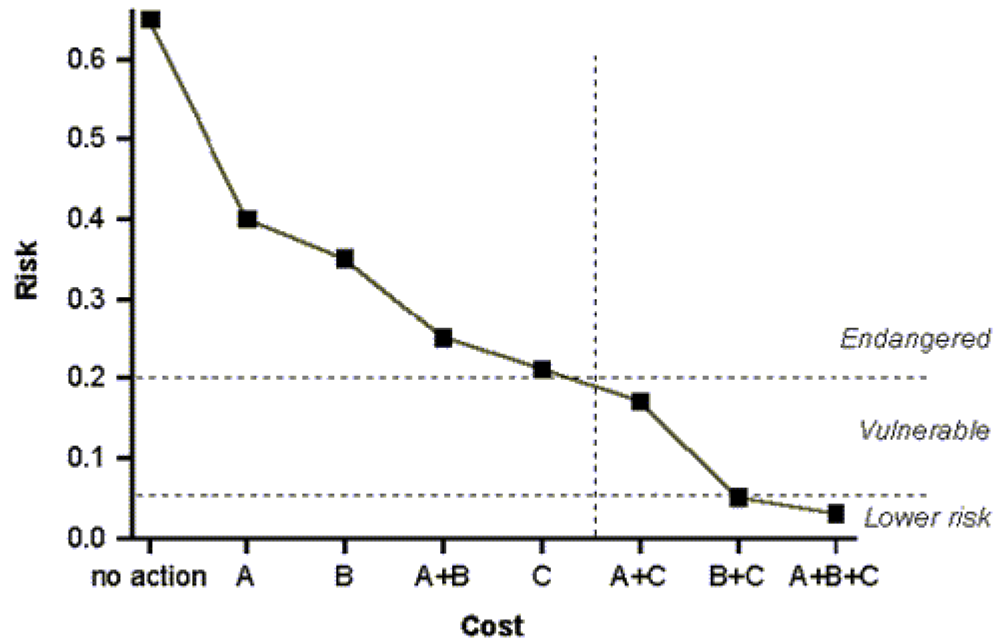
We used RAMAS GIS to identify patches in the habitat suitability map. A habitat patch is a cluster of suitable cells that can support a local gnatcatcher population. The collection of these local populations make up the gnatcatcher metapopulation in the study area. Thus we used the habitat model to calculate the spatial structure of the metapopulation, including size and location of habitat patches and the distances among them. RAMAS GIS also calculated the average and total habitat suitability in each patch.

We combined the spatial structure of the model with demographic parameters (such as survival, fecundity, dispersal, and catastrophes) that we estimated with data from field studies. This resulted in a stage-structured, stochastic, spatially-explicit metapopulation model. Using this model, we simulated the dynamics of the metapopulation under various assumptions.

Results and Future Directions

The results of this model are described in Akçakaya & Atwood (1997).

In the future, we are planning to refine the model, and use it to assess or rank management and conservation alternatives. One type of management that can be evaluated with this kind of a model is habitat conservation and restoration. Suppose, for example, that three of the habitat patches identified in this study are potential candidates for habitat conservation and restoration. If these patches vary in size, then there would a total of 7 alternatives (ranging from restoring only the smallest patch to restoring all three). These, plus the "no action" alternative, can be evaluated by running a series of simulations that incorporate the expected improvements in the carrying capacity and other parameters of the patches where habitat would be restored. The 8 options can then be ranked in order of increasing effectiveness (in, for example, reducing the risk of extinction). For this example, we might expect that the larger the area where habitat is improved, the lower the extinction risk of the gnatcatchers. The obvious choice is to improve the habitat in all three patches. In reality the choices are much less obvious, because improving all three patches may cost more than what is available for California gnatcatcher habitat management, which means we need to consider the costs as well. We could rank the 8 options with respect to both their benefit (reduction in risk of extinction) and with respect to their cost (see Figure below). Such a graph allows the evaluation of each conservation action in terms of costs and benefits, without falling into the trap of assigning a monetary value to the existence of a species.



The effect of habitat conservation and restoration is often modeled as an increase in the carrying capacity for the species. Other types of management can affect other aspect of the demography, for example fecundity. For a demonstration of how two different management actions can be compared, we modeled a hypothetical situation: we compared three different management scenarios: no action, restoration of habitat (increased carrying capacity) and increase in reproduction (increased fecundity). Three sample files that correpond to these three hypothetical management actions are included in a zipped file (gnatmdls.zip) for use with the RAMAS GIS Demo.

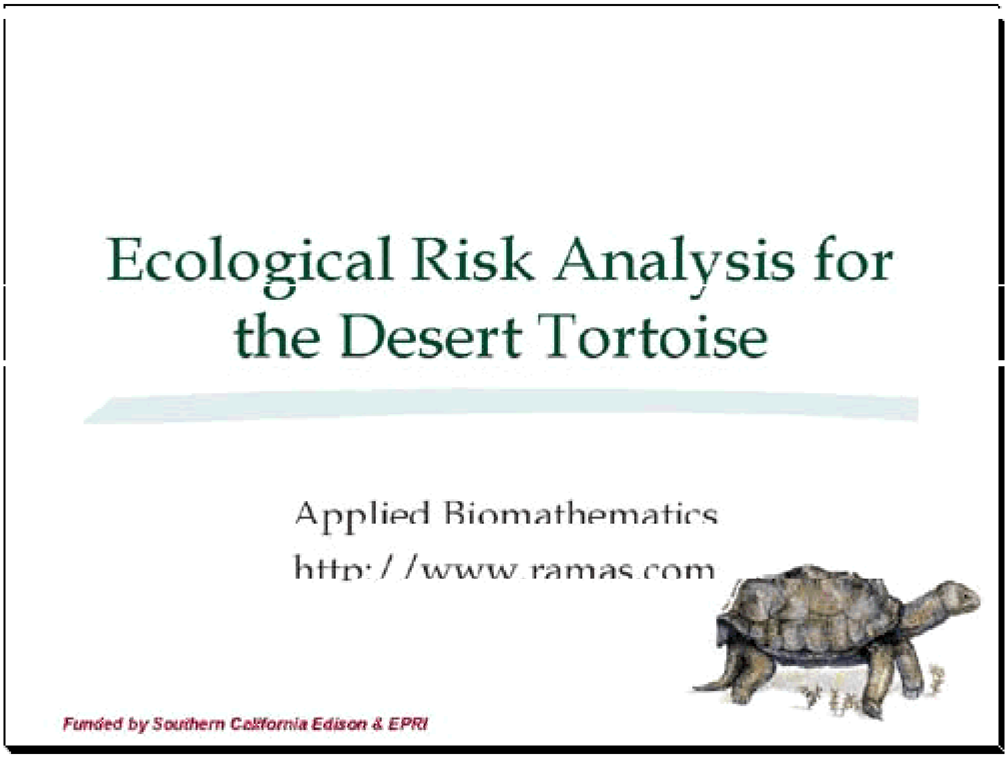
Reference

For more information see:

H. Resit Akçakaya & Jonathan L. Atwood. 1997. A habitat-based metapopulation model of the California Gnatcatcher. *Conservation Biology* 11:422-434.

or

http://www.ramas.com/calgnat.htm

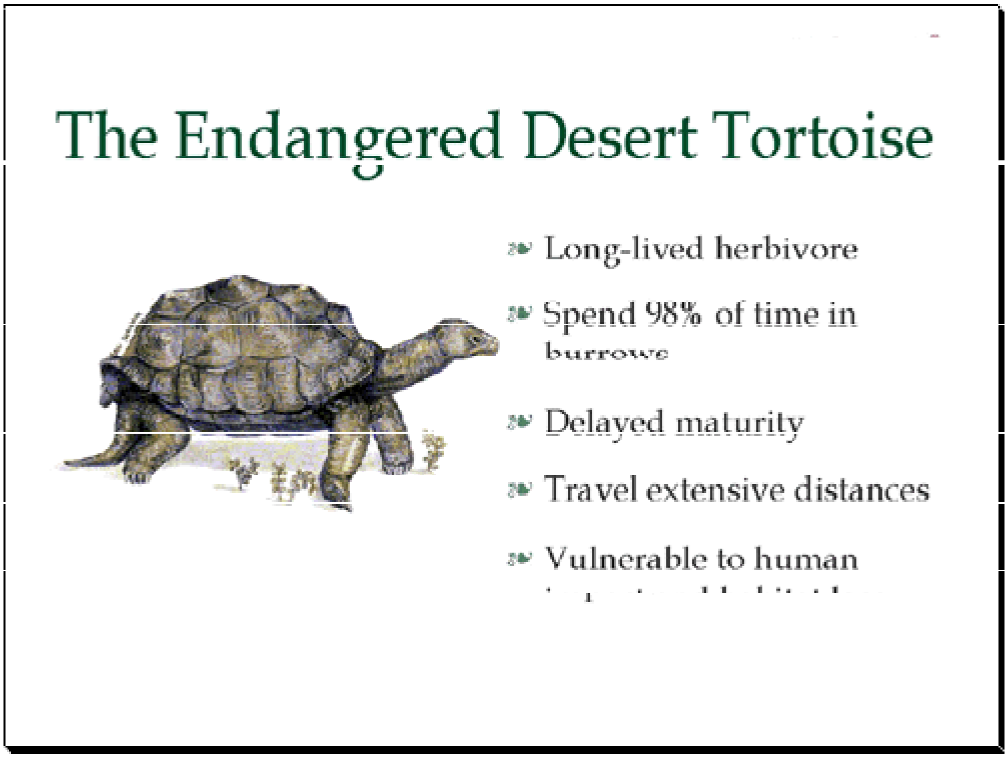


Our goal was to assess the tortoise's long-term prospects.

(click here to go directly to the MODEL*)*

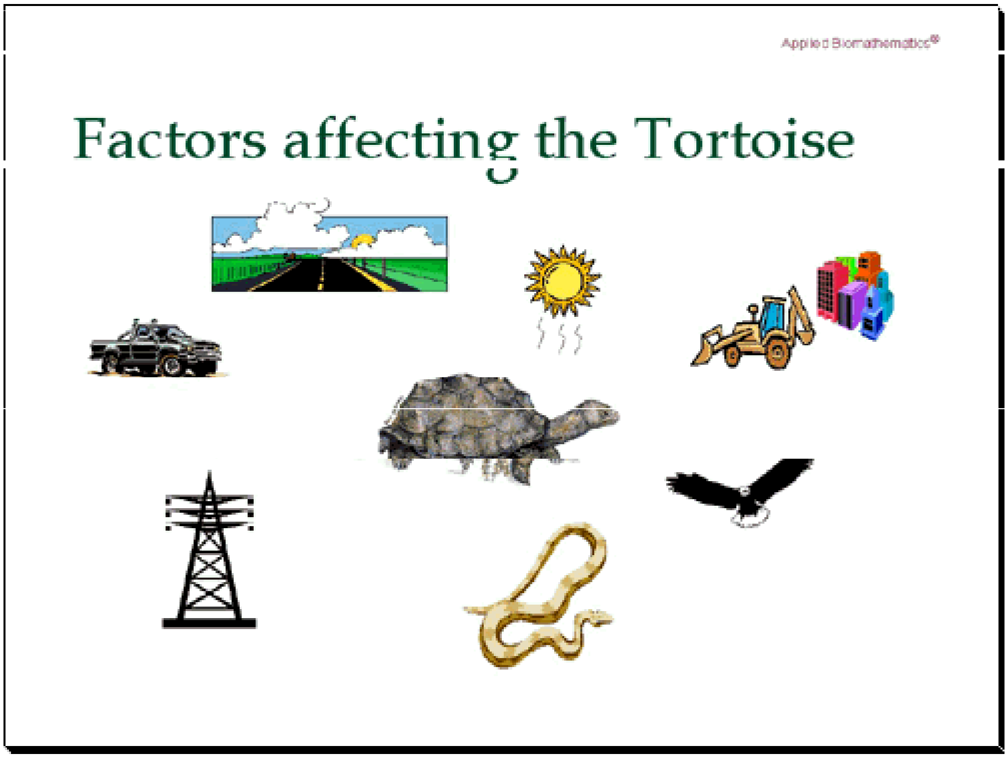
Project Summary

The desert tortoise is a slow-growing, long-lived, species with specific habitat requirements. Human recreation, development, transportation, military activities, energy transmission and mineral extraction have steadily encroached upon the desert habitat. Mounting evidence suggests that the desert tortoise populations are declining throughout the region due to these and many other human influences. In addition, the desert tortoise distribution west of the Colorado has been fragmented into populations that are further subdivided by the lethal barriers of roads and highways. Our approach in this project was to develop a stochastic spatially-explicit metapopulation model to explore population dynamics and the factors that might affect it. We analyzed the existing data on survival, fecundity, density, dispersal and habitat preferences. Population modeling revealed that the assumptions about density dependence used made a difference in the risk of decline that was predicted for the metapopulation. Also the connectivity, i.e., dispersal and fragmentation, among the populations appeared to have a large impact on the risks. Populations that are declining and separated from other populations by roads, are not likely to persist for the next 100 years under conditions similar to the present. The preliminary analysis has been quite useful in identifying critical parameters. This project is ongoing and the model will be designed to allow the evaluation of the impact of various management practices and mitigation measures on the viability of the Desert Tortoise populations, including translocations, raven control, and transmission line siting.



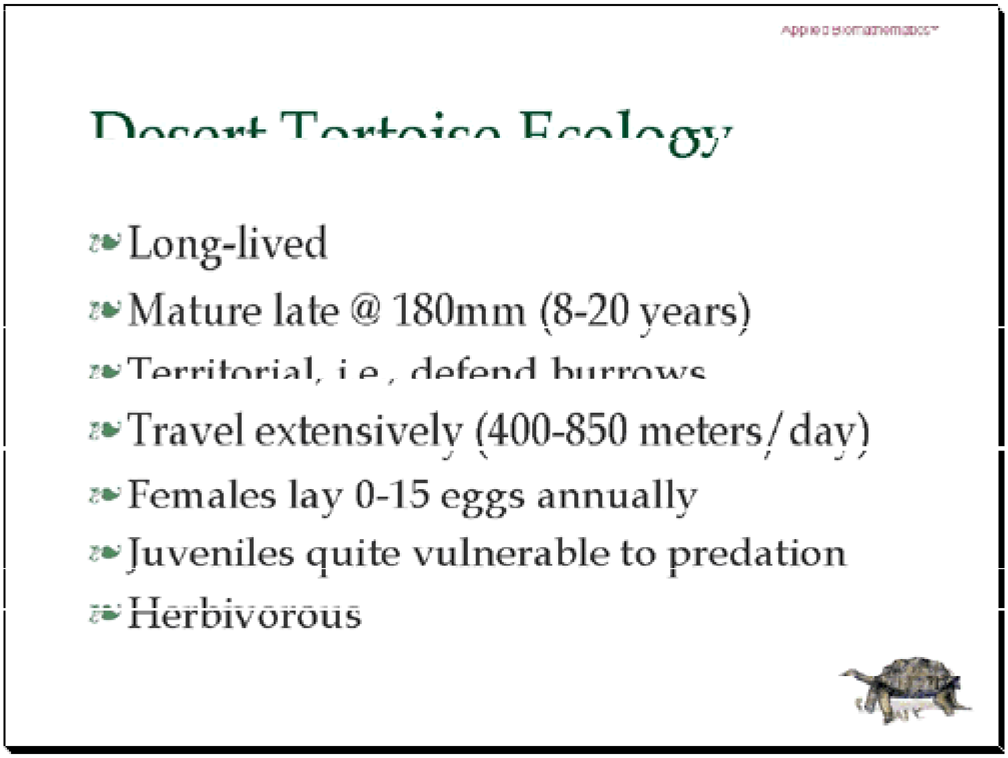
Slide 2: The fundamental problem

The fundamental problem is that the desert tortoise is widely distributed, long-lived and has delayed sexual maturity, making this species vulnerable to human impact and habitat destruction and loss.



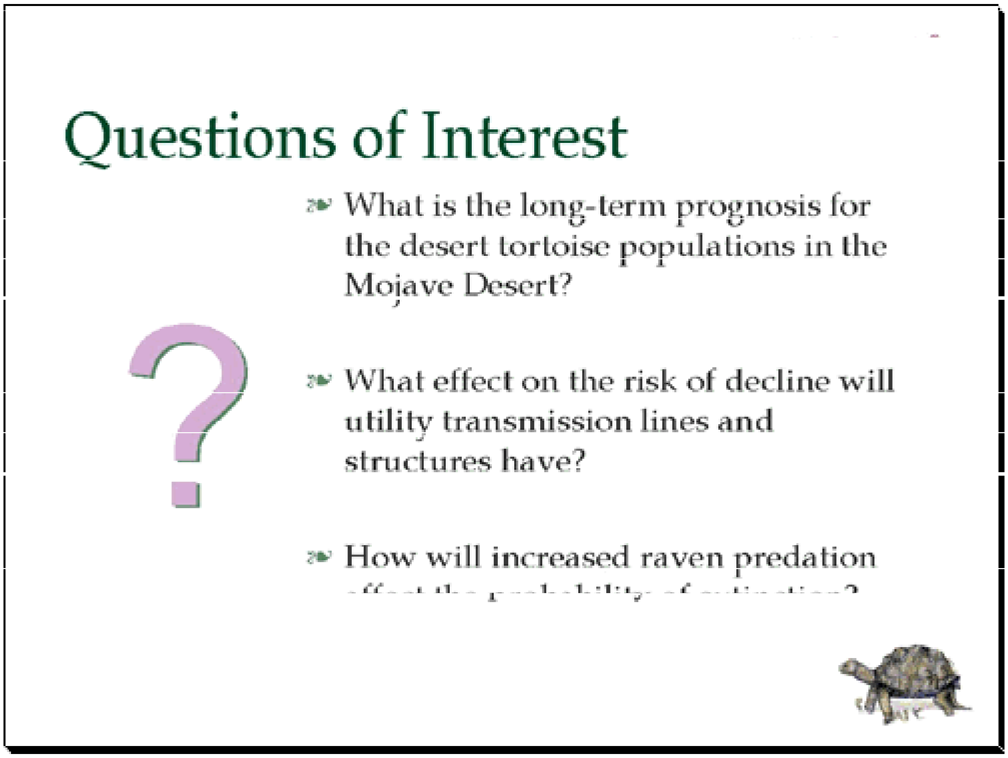
Slide 3: Threatening factors

Many factors affect the long-term viability of the desert tortoise. These include predators, roads, drought, off-road vehicles, raven concentrations along power lines, and construction.



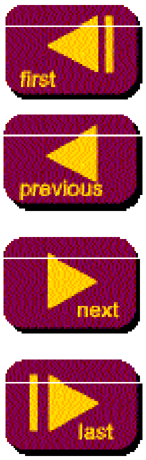
Slide 4: Ecology of the Desert Tortoise

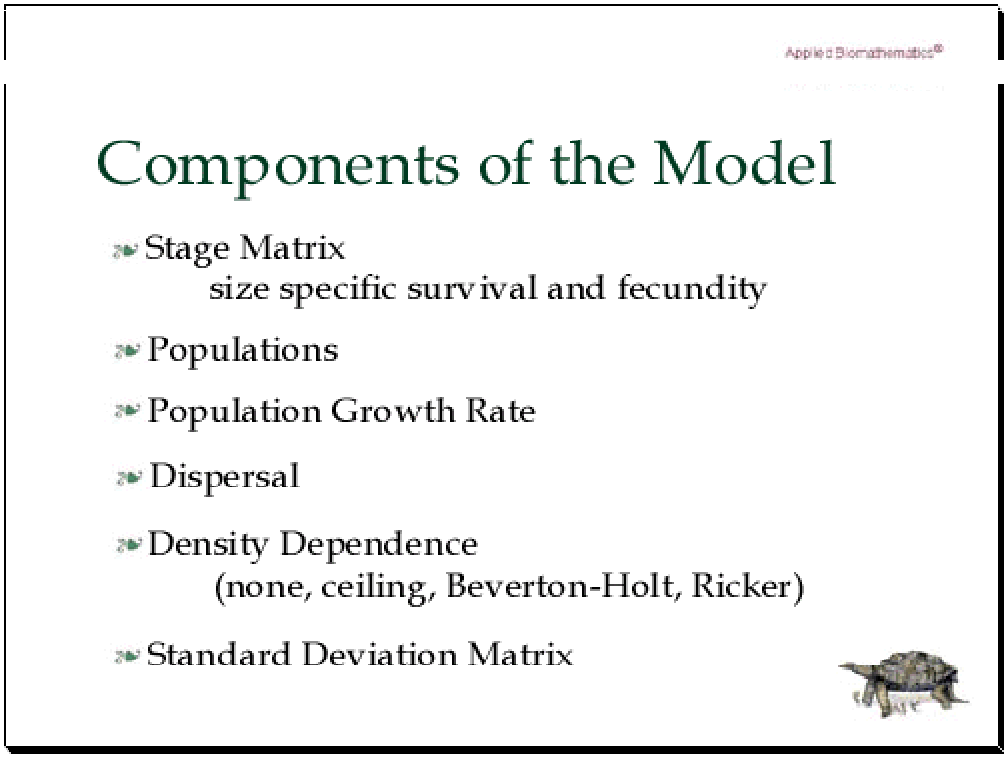
The desert tortoise is a long-lived herbivore that is slow to mature, and travels extensively for mates and food when not resting in its burrow.



Slide 5: The questions of interest

We were interested in assessing the long-term viability for the tortoise metapopulation and the effects of increased fragmentation and predation.



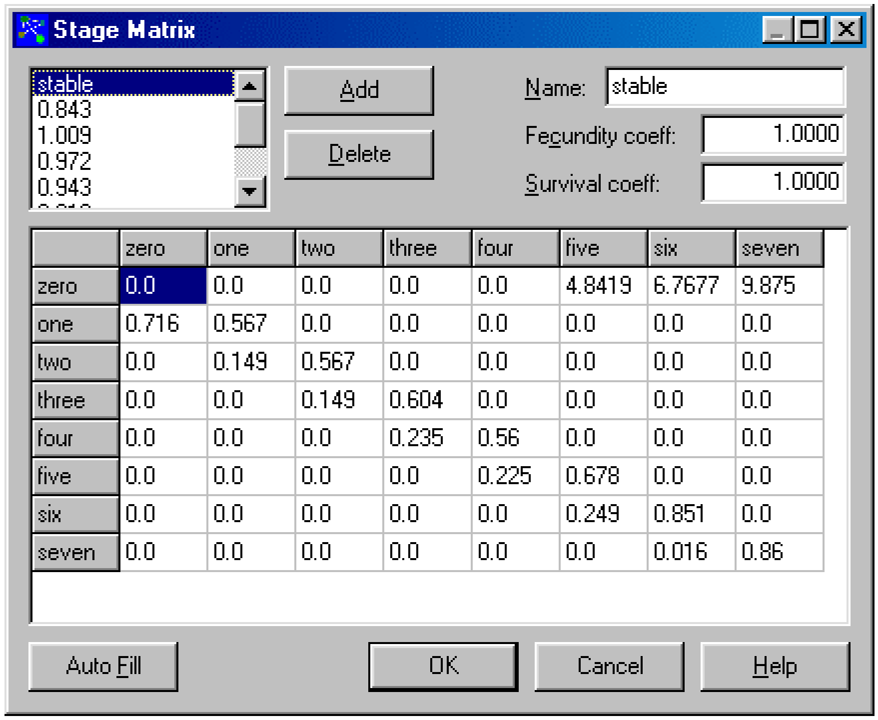


Slide 6: Components of the metapopulation model

Choose a model component in the image above to see more or select from the links below.

MODEL *components:*

1. stage matrix
2. populations
3. population growth rate
4. dispersal
5. density dependence
6. standard deviation



	zero	one	two	three	four	five	six	seven
zero	0.0	0.0	0.0	0.0	0.0	4.8419	6.7677	9.875
one	0.716	0.567	0.0	0.0	0.0	0.0	0.0	0.0
two	0.0	0.149	0.567	0.0	0.0	0.0	0.0	0.0
three	0.0	0.0	0.149	0.604	0.0	0.0	0.0	0.0
four	0.0	0.0	0.0	0.235	0.56	0.0	0.0	0.0
five	0.0	0.0	0.0	0.0	0.225	0.678	0.0	0.0
six	0.0	0.0	0.0	0.0	0.0	0.249	0.851	0.0
seven	0.0	0.0	0.0	0.0	0.0	0.0	0.016	0.86

first
previous
next
last

Slide 7: Stage matrix of the desert tortoise model

Shown above is the stage matrix for the desert tortoise populations. Each population has a stage matrix that is dependent on its annual population growth rate. *click here for more details*

Stage-specific fecundity values are in the first row and stage-specific survival rates are in the other rows.

Details
Project summary
MODEL

Details of vital rates estimation

- Vital rates were estimated based on mark-recapture studies primarily at Goffs, California. (ref)
- *Survival* values (all rows except first) represent the annual probability of surviving from one life history class to the next.
- *Fecundity* in the model is defined as the annual number of surviving hatchlings per female of that class.
- Survival Values remain the same, only the fecundity values (first

row of matrix) change with the different growth rates.

- Each population is assigned a growth rate based on the empirical data.
- With the variability (standard deviation) of the vital rates, a population growth rate of 1.020 is required to achieve a stationary ("stable") population that is neither increasing or decreasing.

	Fecundity		
Population Growth Rate	Class 4	Class 5	Class 6
1.020	4.842	6.768	9.875
1.009	3.984	5.568	8.125
0.972	1.912	2.673	3.900
0.943	0.932	1.302	1.900
0.916	0.405	0.565	0.825
0.914	0.386	0.540	0.788
0.843	0	0	0
0.833	0	0	0

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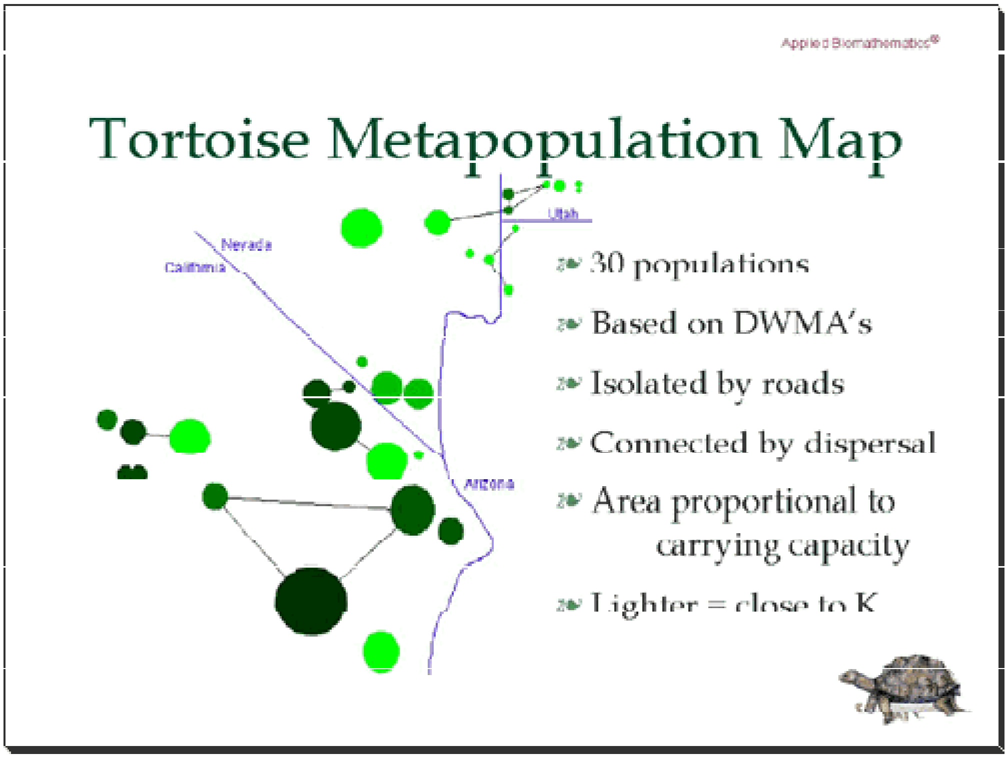


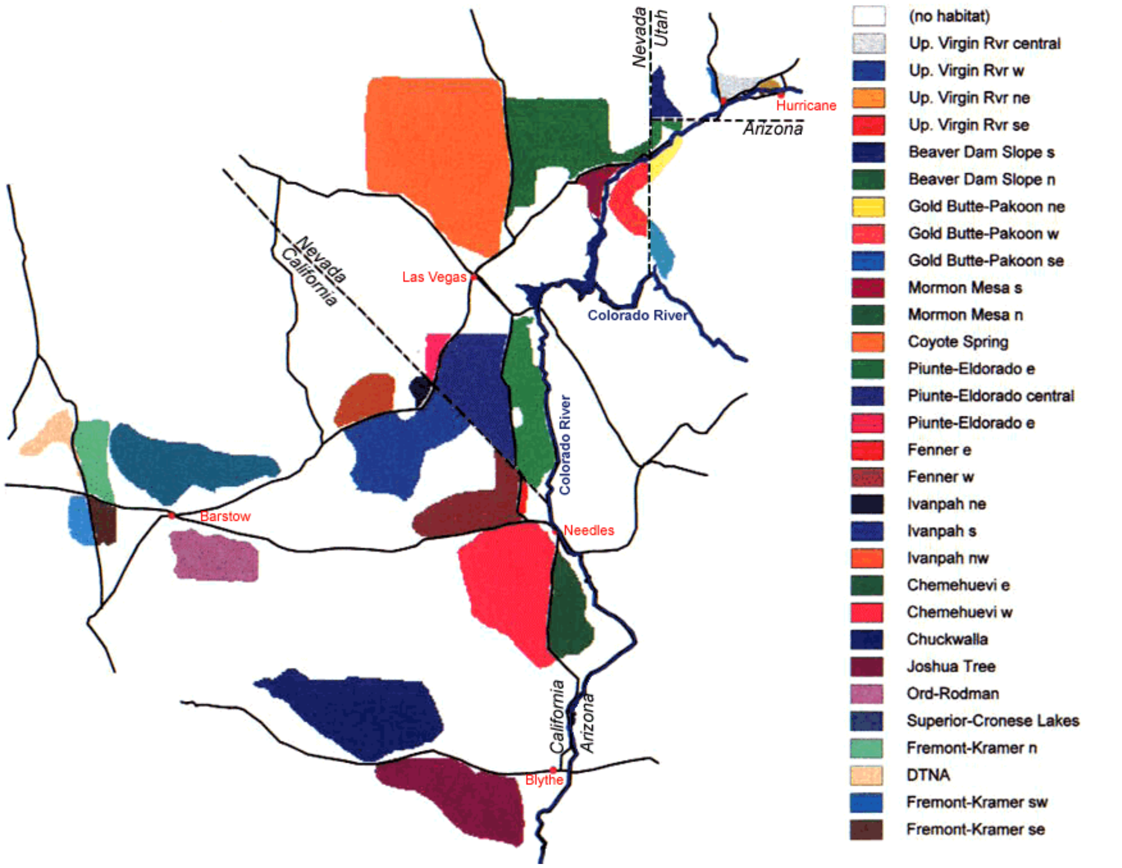
Details
Project summary

Slide 8: The desert tortoise populations

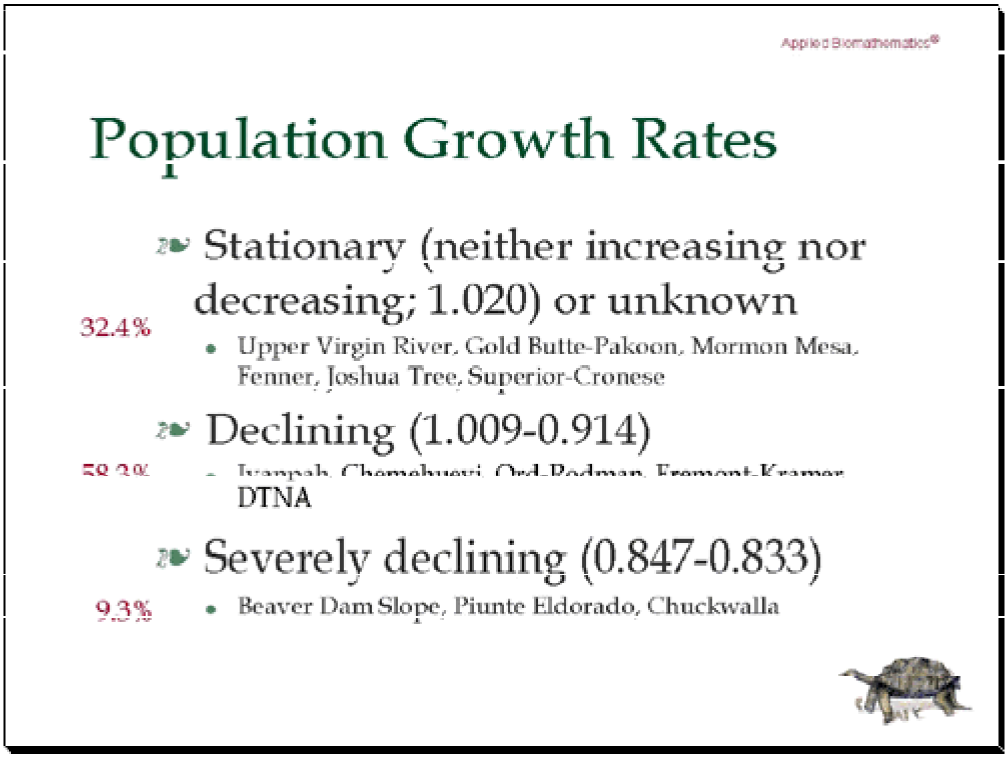
We were interested in assessing the long-term viability for the tortoise metapopulation and the effects of increased fragmentation and predation. (G.I.S. Map)

MODEL

G.I.S. Map showing the location of 30 desert tortoise populations based on the Desert Wildlife Managment Areas (DWMA) designated in the *Desert Tortoise Recovery Plan (1994)*.



Nevada
Utah
Hurricane
Arizona
Nevada
California
Las Vegas
Colorado River
Colorado River
Barstow
Needles
California
Arizona
Blythe
(no habitat)
Up. Virgin Rvr central
Up. Virgin Rvr w
Up. Virgin Rvr ne
Up. Virgin Rvr se
Beaver Dam Slope s
Beaver Dam Slope n
Gold Butte-Pakoon ne
Gold Butte-Pakoon w
Gold Butte-Pakoon se
Mormon Mesa s
Mormon Mesa n
Coyote Spring
Piunte-Eldorado e
Piunte-Eldorado central
Piunte-Eldorado e
Fenner e
Fenner w
Ivanpah ne
Ivanpah s
Ivanpah nw
Chemehuevi e
Chemehuevi w
Chuckwalla
Joshua Tree
Ord-Rodman
Superior-Cronese Lakes
Fremont-Kramer n
DTNA
Fremont-Kramer sw
Fremont-Kramer se



Slide 9: The population growth rates

The population growth rate for each population in the model was based on empirical data. See table below for the specifics.

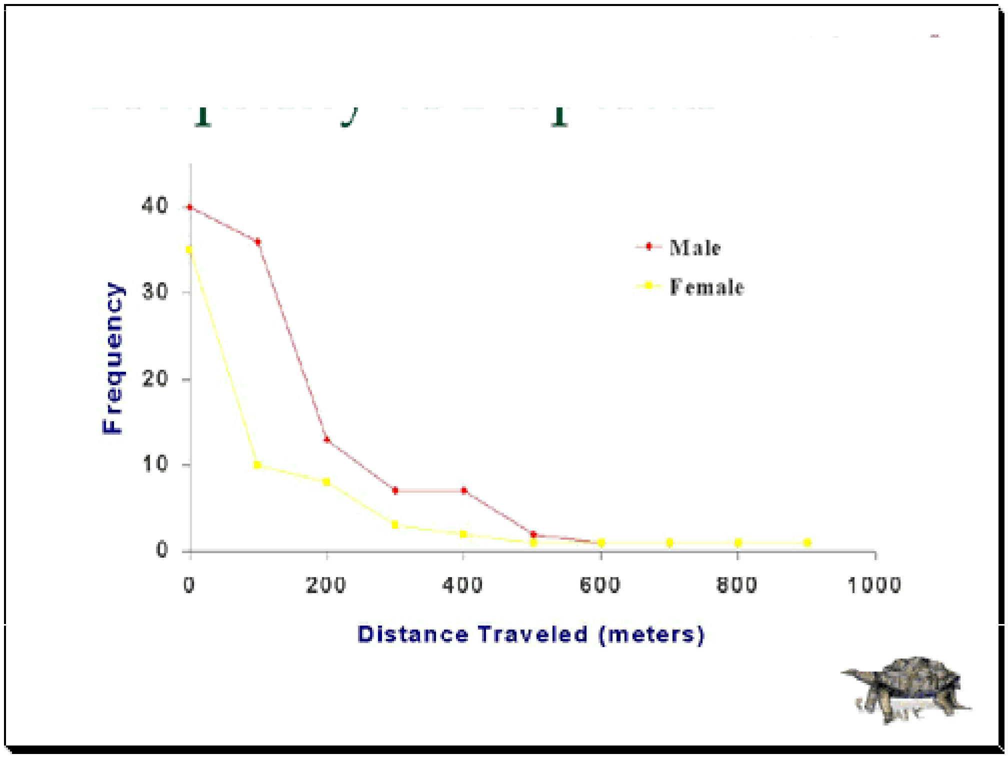
MODEL

Population Growth Rate Details

	Area (km^2)	Initial Abundance	Carrying Capacity	Population Growth Rate
1 Upper Virgin River C	215.2	69678	69678	1.020
2 Upper Virgin River W	47.9	15500	15500	1.020
3 Upper Virgin River NE	52.2	16889	16889	1.020

4	Upper Virgin River SE	19.3	6250	6250	1.020
5	Beaver Dam Slope S	283.4	27375	55044	0.833
6	Beaver Dam Slope N	160.8	15536	31239	0.833
7	Gold Butte-Pakoon N	191.8	14899	14899	1.020
8	Gold Butte-Pakoon W	550.4	42765	42765	1.020
9	Gold Butte-Pakoon SE	263.1	20443	20443	1.020
10	Mormon Mesa S	288.4	33613	33613	1.020
11	Mormon Mesa N	2557.0	298016	298016	1.020
12	Coyote Spring	6109.0	712006	712006	1.020
13	Piunte-Eldorado E	1520.0	268349	368078	0.843
14	Piunte-Eldorado C	1814.9	320420	439500	0.843
15	Piunte-Eldorada NW	199.6	35237	48332	0.843
16	Fenner E	79.3	42809	42809	1.020
17	Fenner W	1351.6	729905	729905	1.020
18	Ivanpah NE	130.6	20037	66451	1.009
19	Ivanpah S	2193.6	336628	1116411	1.009
20	Ivanpah NW	644.1	98848	327826	1.009
21	Chemehuevi E	951.5	98450	276004	0.972
22	Chemehuevi W	2901.8	300251	841756	0.972
23	Chuckwalla	3064.8	477063	2294032	0.843
24	Joshua Tree	2240.2	580202	580202	1.020

25	Ord-Rodman	1146.1	122738	265661	0.972
26	Superior-Cronese	2155.5	697826	697826	1.020
27	Fremont-Kramer N	698.9	71952	284188	0.916
28	DTNA	422.9	85980	185650	0.914
29	Fremont-Kramer SW	298.4	30716	121318	0.916
30	Fremont-Kramer SE	292.2	30079	118803	0.916



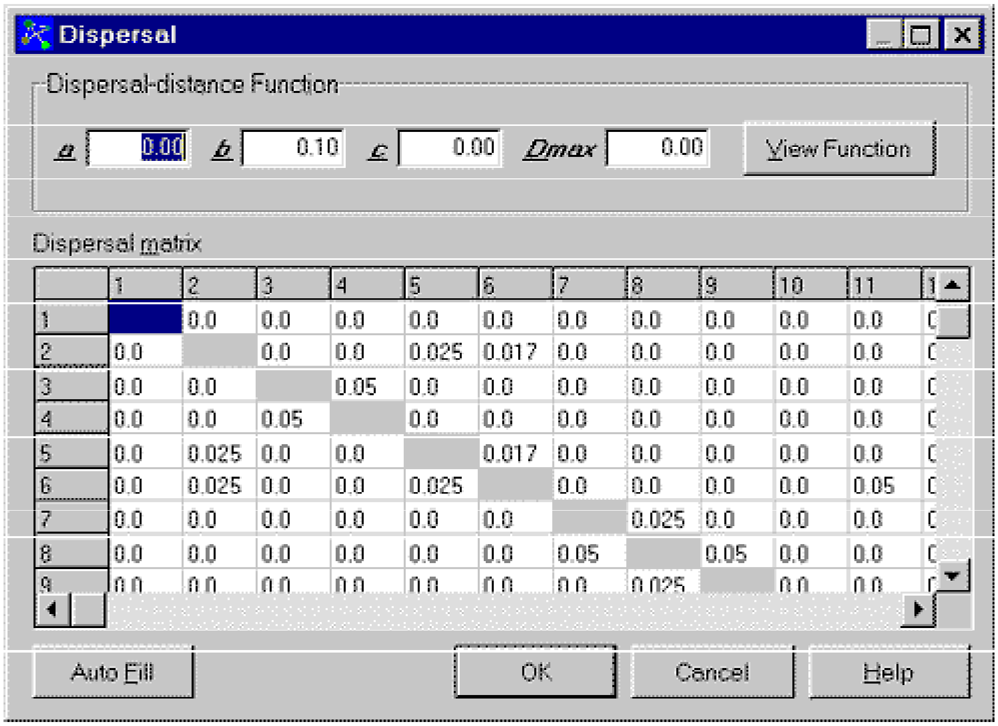
Slide 10: Annual dispersal for the desert tortoise

Shown is a graph illustrating the frequency of dispersal in meters for male and female desert tortoises based on mark-recapture studies (O'Connor et al. 1994).

(example of matrix below)

MODEL

Example of the dispersal matrix in the population model.


Dispersal
Dispersal-distance Function
a 0.00
b 0.10
c 0.00
Dmax 0.00
View Function
Dispersal matrix
1 2 3 4 5 6 7 8 9 10 11
1 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
2 0.0 0.0 0.0 0.025 0.017 0.0 0.0 0.0 0.0 0.0
3 0.0 0.0 0.05 0.0 0.0 0.0 0.0 0.0 0.0 0.0
4 0.0 0.0 0.05 0.0 0.0 0.0 0.0 0.0 0.0 0.0
5 0.0 0.025 0.0 0.0 0.017 0.0 0.0 0.0 0.0 0.0
6 0.0 0.025 0.0 0.0 0.025 0.0 0.0 0.0 0.0 0.05
7 0.0 0.0 0.0 0.0 0.0 0.0 0.025 0.0 0.0 0.0
8 0.0 0.0 0.0 0.0 0.0 0.0 0.05 0.05 0.0 0.0
Auto Fill
OK
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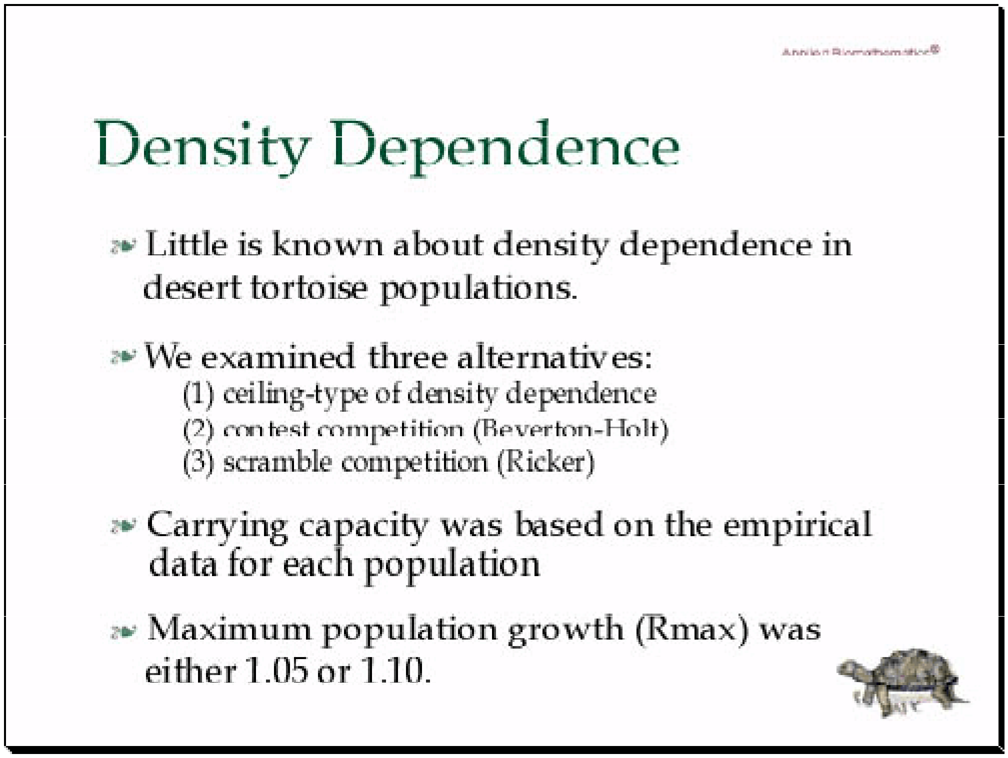
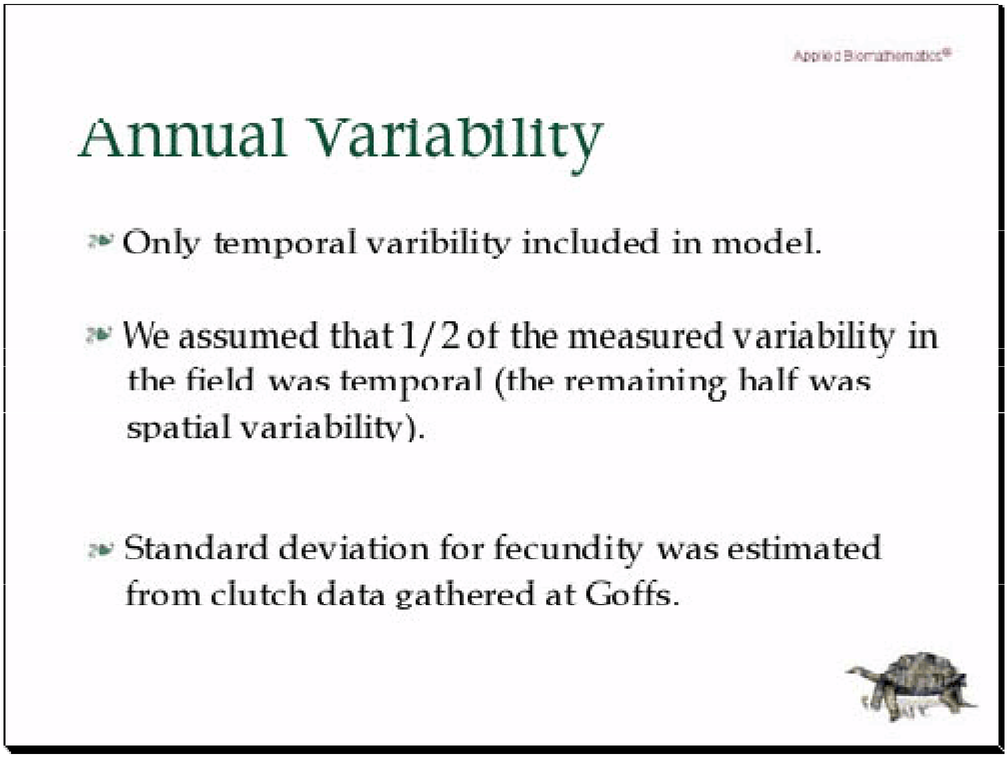


Slide 11: Density dependence for the desert tortoise

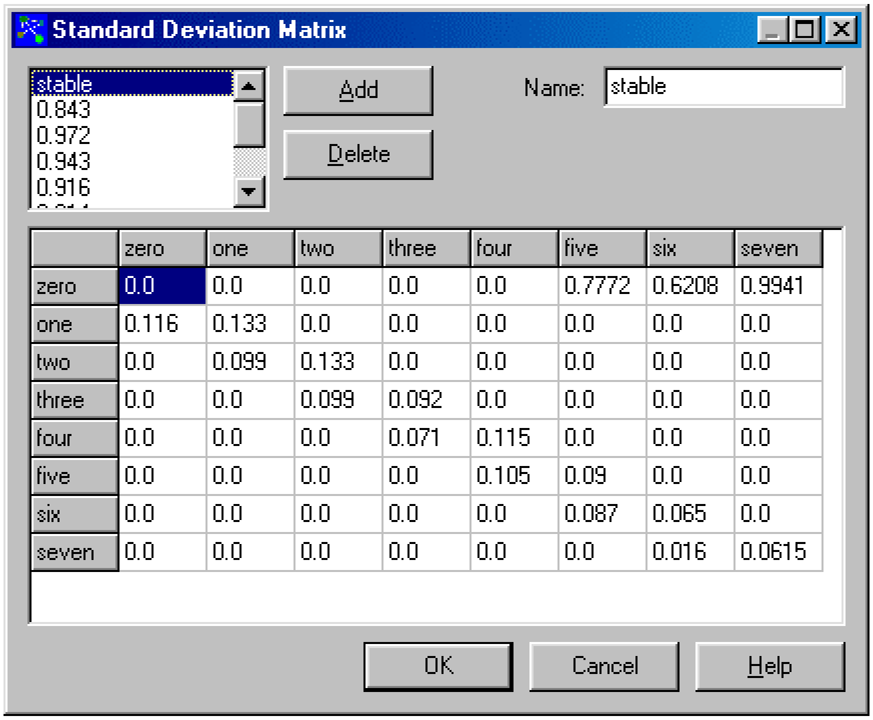
Not very much is known about what type of density dependence operates in desert tortoise populations. Therefore, using the empirical data on the carrying capacity and making the assumption that the maximum growth rate was likely to be 5 or 10% annually, we examined three types of density dependence.



Slide 12: Year-to-year variability in survival and fecundity

Year-to-year variability in survival rates was estimated from the field-measured standard deviations (matrix below). We assumed only 1/2 of the variability was temporal and therefore included in the model. Variability in fecundity was based on clutch data.

Example of the standard deviation matrix under the assumed population growth rate of 1.02.


Standard Deviation Matrix
stable
0.843
0.972
0.943
0.916
Add
Delete
Name:
stable
zero one two three four five six seven
zero 0.0 0.0 0.0 0.0 0.0 0.7772 0.6208 0.9941
one 0.116 0.133 0.0 0.0 0.0 0.0 0.0 0.0
two 0.0 0.099 0.133 0.0 0.0 0.0 0.0 0.0
three 0.0 0.0 0.099 0.092 0.0 0.0 0.0 0.0
four 0.0 0.0 0.0 0.071 0.115 0.0 0.0 0.0
five 0.0 0.0 0.0 0.0 0.105 0.09 0.0 0.0
six 0.0 0.0 0.0 0.0 0.0 0.087 0.065 0.0
seven 0.0 0.0 0.0 0.0 0.0 0.0 0.016 0.0615
OK
Cancel
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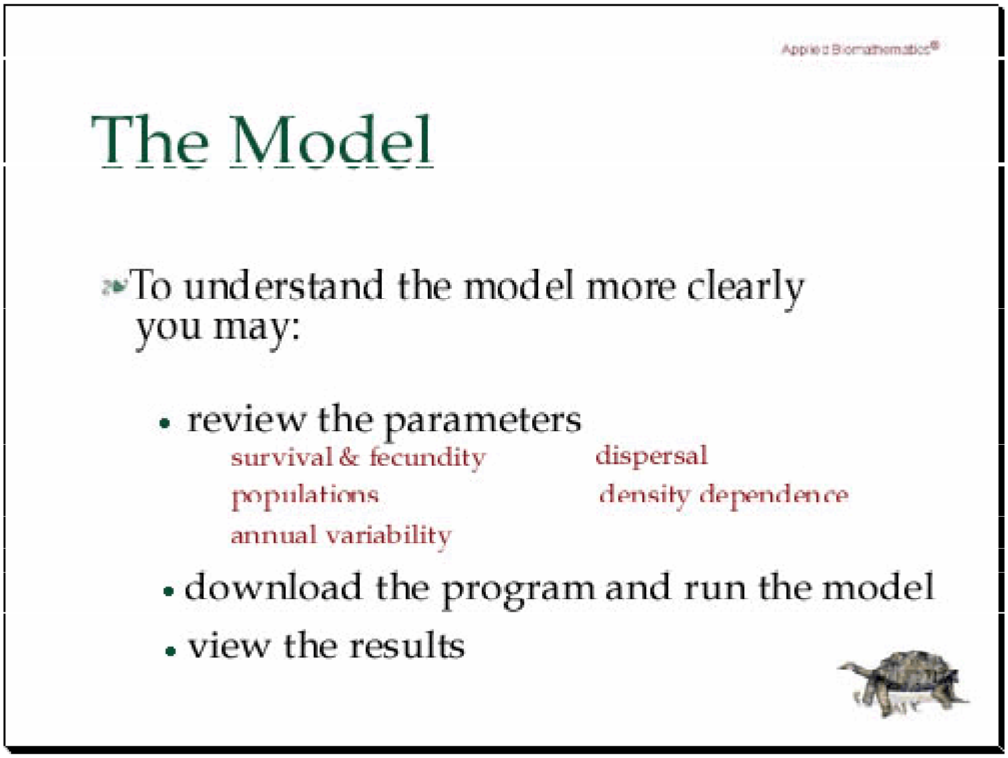


Slide 13: The model for the desert tortoise metapopulation

Select one of the options above to examine the model, download it or view the results.

The Demo Program

Below is a zipped file that contains the RAMAS GIS program and some sample files. Click on the link to download it. (Tortoise sample files)

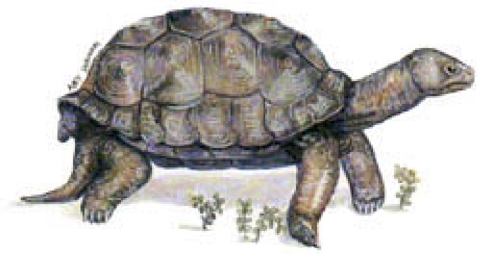
rgdemo.exe (size: 2,441 KB)

Instructions

Instructions for using the demo and its model files. (View instructions as pdf or text file.)

Sample Files

There are two additional sets of sample files:

			Zipped file	Details
1	Desert Tortoise model files		tortmdls.zip	table below or project summary
2	California Gnatcatcher model files		gnatmdls.zip	model page or project summary

---

Desert Tortoise Model Files

Included in the zipped file (tortmdls.zip) are 8 sample model files for the desert tortoise with the following parameters:

(for more information about a parameter click on it.)

File	Density Dependence	Rmax	Dispersal
Tceil.mp	Ceiling type	-	yes
Tceilno.mp	Ceiling type	-	no
Tcont5.mp	Contest competition	1.05	yes
Tcont10.mp	Contest competition	1.10	yes
Tct10no.mp	Contest competition	1.10	no
Tscr5.mp	Scramble competition	1.05	yes

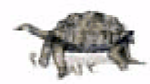
Tscr5.mp	Scramble competition	1.05	yes
Tscr10.mp	Scramble competition	1.10	yes
Tscr10no.mp	Scramble competition	1.10	no

first
previous
next
last

Applied Biomathematics®

Results of the Model

	Rmax	Dispersal	Terminal Risk Declining in Abundance by: 50%	80%	100%
Ceiling		yes	1.00	0.85	0
Contest	1.05	yes	0.99	0.58	0
Contest	1.10	yes	0.92	0.05	0
Scramble	1.05	yes	0.99	0.57	0
Scramble	1.10	yes	0.92	0.04	0
Ceiling		no	1.00	0.86	0
Contest	1.10	no	0.92	0.02	0
Scramble	1.10	no	0.92	0.02	0

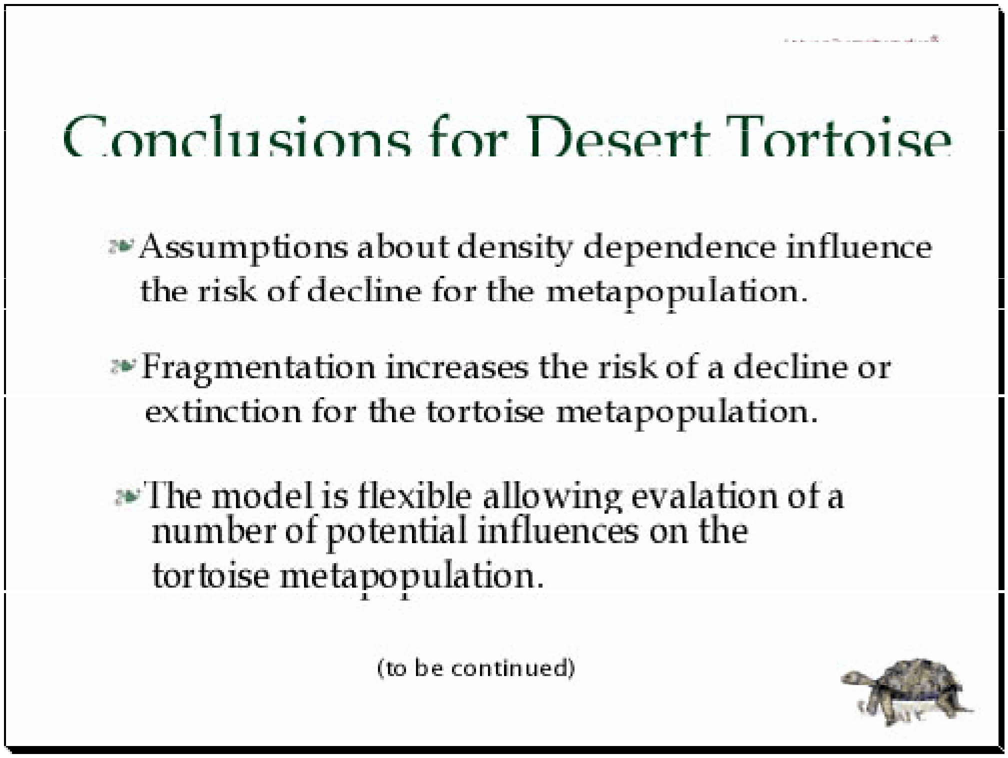


Slide 14: The results of the metapopulation model for the desert tortoise

- 16 of the 30 populations are declining because of their growth rate
- if density dependence operates as a simple limit (ceiling), the risk of a decline is high
- the risk of a decline is less with scramble or contest competition
- the risk of a decline is reduced if there is no dispersal among populations

Project summary

MODEL



Slide 15: Conclusions

- Preliminary results of this model suggest that assuming a competition type of density dependence decreases the risk of a decline.
- Fragmentation increases the risk of extinction as the declining populations siphon individuals from the stable or increasing populations.
- The model is quite flexible. It can adapt to additional data as they become available. It can also evaluate a variety of impacts on the metapopulation.
- This work is part of an ongoing research effort. We are now examining the effects of road building and transmission line siting as well as the effects of increased raven predation.

first
previous
Project summary

MODEL

Instructions for Installing and Using RAMAS GIS® (demo version)

(view as a pdf or text file)

Contents:

About the Program

RAMAS GIS is designed to link GIS-generated landscape data to a metapopulation model for extinction risk assessment, viability analysis, reserve design and wildlife management. It combines spatial data on the landscape with habitat requirements of the species and demographic data on its population dynamics into a metapopulation model. This model can then be run to simulate future changes in the abundance of the species and its distribution in the landscape, to estimate the risk of extinction or decline, time to extinction and other measures of threat and viability.

RAMAS GIS consists of five component programs: Landscape Data, Habitat Dynamics, Metapopulation Model, Sensitivity Analysis, and Comparison of Results. The use of each of these programs is discussed below. All of the components can be accessed by running a shell program (RAMASGIS.exe).

Requirements

The program requires an IBM-compatible personal computer, running Microsoft Windows 95. It also works under Windows NT 4, although we have not extensively tested the software under Windows NT. The program will not work under Windows 3 or 3.1.

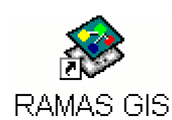
Memory:	The program requires at least 16 megabytes of memory. More memory would improve performance.
Processor:	The program will run on an 80486 processor, although we recommend a Pentium or faster processor.
Hard disk space:	The program requires approximately 4 megabytes of hard disk space.

Installation of RAMAS GIS

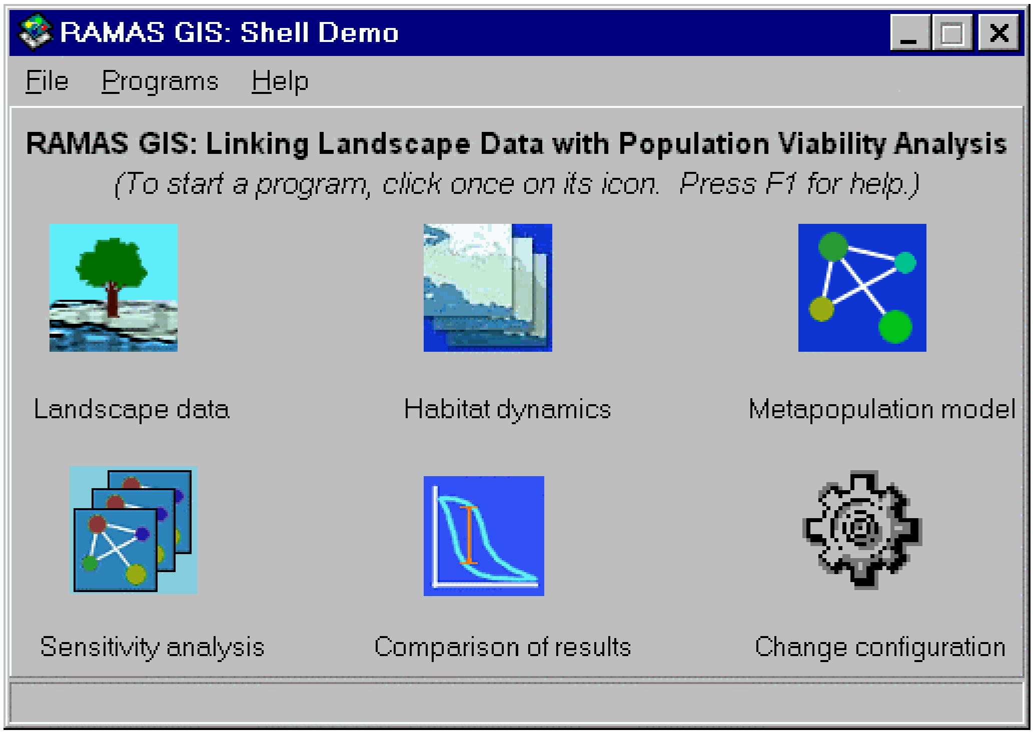
Download RAMAS GIS and save to your hard drive. Double-click on the file installdemo.exe to start the installation program. Follow the instructions on the screen.

By default, RAMAS GIS will be installed in your computer's "Program Files" folder. Also, the installation program will place a RAMAS GIS program icon on your desktop that you may double-click to start the program.

Running the Program

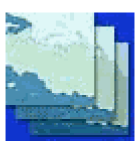
Double-click on the RAMAS GIS icon 

on your desktop to start the program. Press the F1 button on your keyboard for help. You can also start RAMAS GIS from the "RAMAS GIS" group under "Programs" in the Start menu, or by double-clicking on the icons of associated data files (.PTC, .PDY, and .MP).

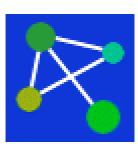


Opening this shell allows you to start any of six component programs. You may start a program by clicking on its icon or selecting the name of the program from the *Programs* menu. Below is a description of each of the programs.

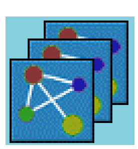
LANDSCAPE DATA lets you sample import and analyze habitat data, on which the spatial structure can be based.



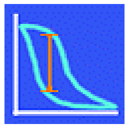
HABITAT DYNAMICS is designed to model temporal changes in habitat. It lets you estimate carrying capacities and/or vital rates for each population as a time series.



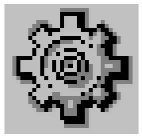
METAPOPULATION MODEL lets you build metapopulation models with spatial structure. These models can have variability, density dependence, and migration among populations.



SENSITIVITY ANALYSIS lets you automatically or manually run multiple simulations within the Metapopulation model component program.



COMPARISON OF RESULTS lets you compare results from different simulations by superimposing results. It can also be used to view the results of a sensitivity analysis, to evaluate management options, to compare alternative models, or to assess anthropogenic impact.

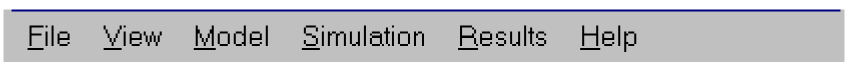


CHANGE CONFIGURATION lets you set many of the defaults for the program and save to a configuration file that is automatically loaded whenever you start RAMAS GIS.

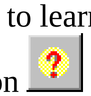
The use of the first five programs is very similar. Each program's main window consists of (1) title bar, (2) menu bar, (3) tool bar, (4) model summary, and (5) status bar.

(1) *Title bar*: At the top of the window is the title bar with the program name. On the title bar, at the upper-right corner of the window, are three buttons for minimizing  , maximizing (or restoring to original size), and closing  the main program window . Clicking the close button will terminate the program.

(2) *Menu bar*: Below the title bar is the menu bar, which includes 5 or 6 menus:



Click on one of these 6 words to open the pull-down menu. Alternatively, you can press the *Alt* key in combination with the underlined letter in the menu name. For example, pressing *Alt-M* will open the *Model* menu.

Shown is the title bar for the Metapopulation Model program. *File* menu is used to open or save model files. *View* menu is used to set display options. Selecting each item in the *Model* menu opens a dialog box that includes a group of model parameters. *Simulation* menu is used to run a simulation. After running a simulation, selecting each item in the *Results* menu displays one type of model result. The entries listed under *Model* and *Results* menus depend on the program. In each program, click "Help" to learn more about the operation of the program or click on the question mark icon  found in some of the windows.

(3) *Toolbar*: Below the menu bar is the toolbar, which includes 4 buttons that can be used as shortcuts to access the following functions found under the File menu: (Note that the *New*, *Save*, and *Print* options are disabled in the demo version.)

New (start a new model; same as pressing *Ctrl-N*)

Open (open an existing model; same as pressing *Ctrl-O*)

Save (save the model in a file; same as pressing *Ctrl-S*)

Exit (close the program; same as pressing *Alt-X*)

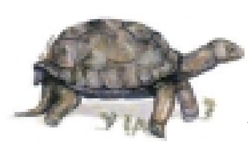
(4) *Status bar*: At the bottom of the main program window is the status bar, which displays information about what the program is doing, as well as hints.

You can resize the program window by clicking on the lower-right corner of the window and dragging. Some of the selections in the menus of a program (for example *Run*) are procedures, and selecting them will make the program start computing. Others are dialog boxes for entering input parameters or displaying results. When you select one of the dialog boxes for input, the program will display a template on which you can type the values of the various parameters. After you enter your parameters, click *OK*. If you want to leave a dialog box without making any changes to the input data, click *Cancel*, and the changes you have made since you opened the dialog box will be ignored. For help about input parameters, click *Help* (or press *F1*).

(**Note: for the demo version you must click *Cancel* or the *X* in the upper right hand corner of the window since no changes may be saved. Clicking *OK* will bring up an error message.**)

Loading input files

In each program, you can load sample files. To do this, select *Open* from the *File* menu (or, press *Ctrl-O*), type in the filename or select a file by clicking. Included with the demo are the eight Desert Tortoise Model files shown in the table below. You may open any of these directly or through the *Open* command in the *File* menu.



Desert Tortoise Examples

File Name	Density Dependence	Rmax	Dispersal
Tceil.mp	Ceiling type	n/a	yes

Tceil.mp	Ceiling type	n/a	yes
Tceilno.mp	Ceiling type	n/a	no
Tcont5.mp	Contest competition	1.05	yes
Tcont10.mp	Contest competition	1.10	yes
Tct10no.mp	Contest competition	1.10	no
Tscr5.mp	Scramble competition	1.05	yes
Tscr10.mp	Scramble competition	1.10	yes
Tscr10no.mp	Scramble competition	1.10	no


California Gnatcatcher Examples

File Name	Management Action	Parameter Change
NoAction.mp	none	none
LargerK.mp	restoration of habitat	increased carrying capacity
HighFecundity.mp	increased reproduction	increased fecundity

Saving models and results (DISABLED IN DEMO)

In each program, you can save a model you have created or modified. To do this, select *Save as* (to save a model with a different name) or *Save* (to save with the same filename) from the *File* menu. If you have already run the model, the results will also be saved.

Entering data (CHANGES CANNOT BE SAVED IN DEMO)

Within input windows, (such as *General Information* in the *Model* menu), you can type in parameter values, as well as title and comments. In all subprograms, the number of time steps (duration) and the number of replications are entered in *General Information*.

Setting replications to **0** is a convenient way of making the program run a deterministic simulation, even if the standard deviation of the growth rate is greater than zero. When the number of replications is specified as **0**, the program assumes a deterministic simulation, and ignores parameters related to stochasticity. These parameters include the standard deviation matrix for age- or stage-structured models, and the parameters that are dimmed (not available for editing) in other input windows.

Erasing all input data and all results (DISABLED IN DEMO)

To erase all input parameters and all results of a model, simply start a new model. You can do this by selecting New from the File menu.

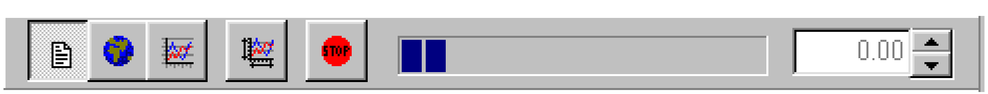
Using the help

The function key F1 provides access to a context-sensitive help facility. You can press or click the Help button anytime to get help about a particular window. In the help facility, click on a topic and click Open.

Running a simulation

After you have loaded a file, or created a model, you can run a simulation by selecting Run from the Simulation menu (or by pressing Ctrl-R). When the simulation starts, the program will open a Simulation window.

There are several controls on the toolbar at the top of the Simulation window.



The first three buttons on the left (right under the word "Simulation" in the title) allow you to choose the simulation display (what to display during a simulation).

By the default, the program will display text or the metapopulation map , depending on the program. The third button from the left will display the trajectories .

For unstructured and age- or stage-structured models, the program will display the population trajectory simulated by each replication. For metapopulation models, the program will display a map of the metapopulation, and will update the map at every time step. The display of trajectories or maps may slow down the program. To turn off the display, click the first button from the left on the toolbar. This will display only text (title, comments, and other parameters) during a simulation. This allows the simulation to be completed faster.

When a simulation is completed, you will see "End of simulation" at the bottom of the window. Close the Simulation window (click on the X in the upper-right corner) to return to the main window. Once you return to the main window, you cannot go back to the display of individual trajectories (unless you run the simulation again).

Viewing and printing results

To view or print the results of a simulation, select one of the entries under the Results menu. This will open a window and display a graph. On top of the window is a series of buttons that will:

show a plot (display the result graphically, which is the default)

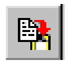
show numbers (display the result as a numerical table)

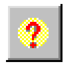
open a window for changing the scale and titles of the graph

save the result as a disk file

print the result (plot or text) on the default Windows printer

copy the result to the clipboard, for pasting into another application

 copy the result to the clipboard, for pasting into another application

 display help for the particular result

When a graph is displayed, the axes may have the letters *k*, *m*, or *b*. These indicate the multiplication factors:

k = x 1,000

m = x 1,000,000

b = x 1,000,000,000

Thus 2.50*k* means 2500 and 0.2*m* means 200,000.

RAMAS GIS tries to pick sensible scales for graphs, but you may want to alter them. You may also want to change the title and the axis labels. You can do this by clicking the "Scale" button in the window that contains your graph (the third button from the left). To change the title, the x-axis label, or the y-axis label, simply click the mouse in the box with the element to be changed, and use the keyboard to edit it. If you want to change the scale of either the x-axis or the y-axis, you must make sure that "Autoscale" is not selected (i.e., the check mark must not be there). If it is selected, simply click on "Autoscale" and the check mark will disappear. At this point, you may click on the number to be changed and edit it.

Exiting the program

To exit from one of the component programs, select *Exit* from the *File* menu.

The Component Programs

RAMAS GIS contains six component programs. The major features of these programs are described below. For detailed descriptions of the commands and their usage use the help function within the program. Not all of the features are enabled in the demonstration version of RAMAS GIS that are available in the commercial version. In addition, there is a three month limit to the use of the demonstration version. Contact Applied Biomathematics (see Technical Support) for assistance in purchasing the commercial version.

LANDSCAPE DATA

The landscape data program is designed for viewing G.I.S. data and analyzing habitat characteristics. You may open sample IDRISI image files (*.img or *.ptc), examine the habitat suitability functions, and run the patch detection function.

You may also view various habitat parameters such a habitat suitability maps and histograms, carrying capacity, initial abundance, and patch parameters such as area, edge, shape index and fractal dimension. For example, you may open Gnatcatcher.ptc and examine the habitat suitability map that is incorporated in all of the California gnatcatcher example files. The New, Save, and Save As commands are disabled in the demo so that no new G.I.S. maps may be imported and no changes may be saved.

HABITAT DYNAMICS

The Habitat Dynamics program is designed to model temporal changes in habitats, i.e., you can specify changes in the habitat characteristics in terms of the Landscape data files, and the time step at which they become effective. You may open habitat data files (*.pdy) and examine the input files. No changes in carrying capacity, survival or fecundity can be run in the demo (Run will result in an error message). Also, the New, Save, and Save As commands are disabled in the demo so that no new G.I.S. maps may be imported and no changes may be saved.

METAPOPULATION MODEL

The Metapopulation Model program is designed for constructing and running metapopulation models with spatial structure. Demographic parameters such as survival and fecundity are entered as a transition matrix with a corresponding standard deviation matrix. The number and characteristics (i.e., location, density dependence, initial abundance, etc) of each population may be specified individually. Dispersal and correlation among populations is specified in a population matrix either entered manually or as a function. Population management strategies such as harvesting, introduction, and translocation as well as catastrophes can be specified for each population. Results of the simulations may be displayed in a variety of ways such as the trajectory summary, harvest summary, population structure, final stage abundances, metapopulation occupancy, local extinction duration, interval and terminal extinction risks, interval and terminal explosion risks, interval and terminal percent declines, and times to quasi-extinction or explosion. The New, Save, and Save As commands are disabled in the demo so that no new G.I.S. maps may be imported and no model parameter changes may be saved.

SENSITIVITY ANALYSIS

The Sensitivity Analysis program is designed to run automatically or manually (user-specified) metapopulation models. Neither the Manual nor Automatic sensitivity analysis options are enabled in the demo.

COMPARISON OF RESULTS

The Comparison of Results program is designed to compare the results from different simulations by superimposing results. You may load any metapopulation model files (*.mp) that have results and compare directly a number of result options. The results include the trajectory summaries, harvest summaries, population structure, final stage abundances, metapopulation occupancy, local occupancy, local extinction duration, interval and terminal extinction risks, interval and terminal explosion risks, interval and terminal percent declines, and times to quasi-extinction or quasi-explosion.

CHANGE CONFIGURATION

The Change Configuration program is designed to let the user set the defaults for the program. These default values include the number of populations, the number of replications, the number of input maps, the number of stages and stage matrices etc. A set of default values can be saved as a file that is automatically opened when the program begins. This program is particularly useful when computer memory for running the program is limited because it allows you to minimize the features that are not needed and maximize those of interest.

Technical Support

User support from Applied Biomathematics is limited to technical aspects of using the program. The RAMAS home page has a list of frequently asked questions. If you want to contact us, please indicate the program and model you are using, describe the question or difficulty in detail, and if possible, attach a copy of the input file you were working on.

homepage:	http://www.ramas.com
e-mail:	GIS@ramas.com
address:	100 North Country Road, Setauket, NY 11733 USA

The Model for the California Gnatcatcher

The Demo Program

Below is a zipped file that contains the RAMAS GIS program and some sample files. Click on the link to download it. (Gnatcatcher sample files)

rgdemo.exe (size: 2,441 KB)

Instructions

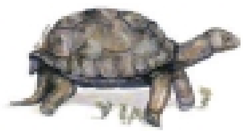
Instructions for using the demo and its model files. (View instructions as pdf or text file.)

Tutorial for using the gnatcatcher files with the RAMAS demo program.

Sample Files

There are two additional sets of sample files:

			Zipped file	Details
1	California Gnatcatcher model files		gnatmdls.zip	table below or project summary or tutorial

2 Desert Tortoise model files		tortmdls.zip	model page or project summary

California Gnatcatcher Model Files

Included in the California Gnatcatcher zipped file (gnatmdls.zip) are 3 sample model files for the gnatcatcher with the following parameters:

File	Management Action	Parameter Change
NoAction.mp	none	none
LargerK.mp	restoration of habitat	increased carrying capacity
HighFecundity.mp	increase reproduction	increased fecundity

These sample files are intended as a demonstration of how different management actions can be compared. They describe three hypothetical management scenarios: no action, restoration of habitat (increased carrying capacity) and increase in reproduction (increased fecundity).

For more information about the project click here.

California Gnatcatcher Models: A Tutorial

RAMAS GIS Demo

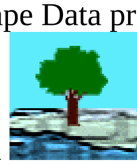
Begin by

1. Downloading the demo program
2. Installing the program
3. Downloading the gnatcatcher files
4. Reviewing the instructions

The Gnatcatcher Models

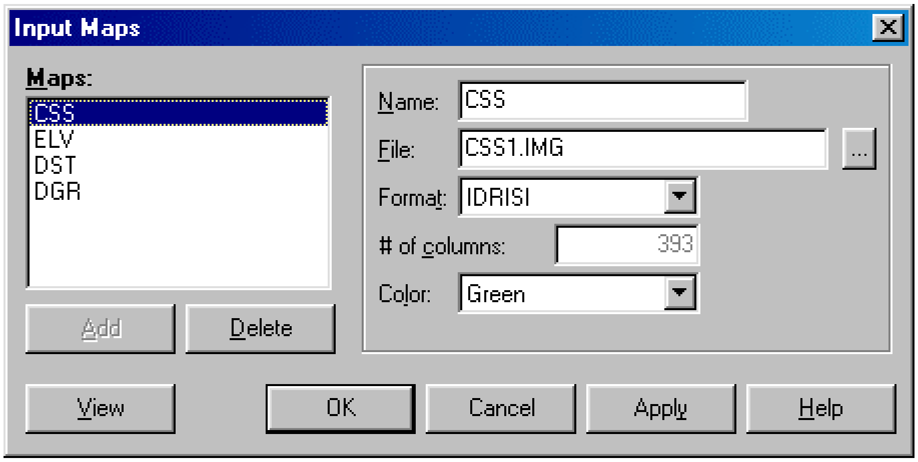
Habitat Suitability Analysis

1. Start the Landscape Data program from the program shell.

   Click on the icon .

2. Open the file Gnatcatcher.ptc using the *Open* command in the *File* menu or using *Ctrl-O*.

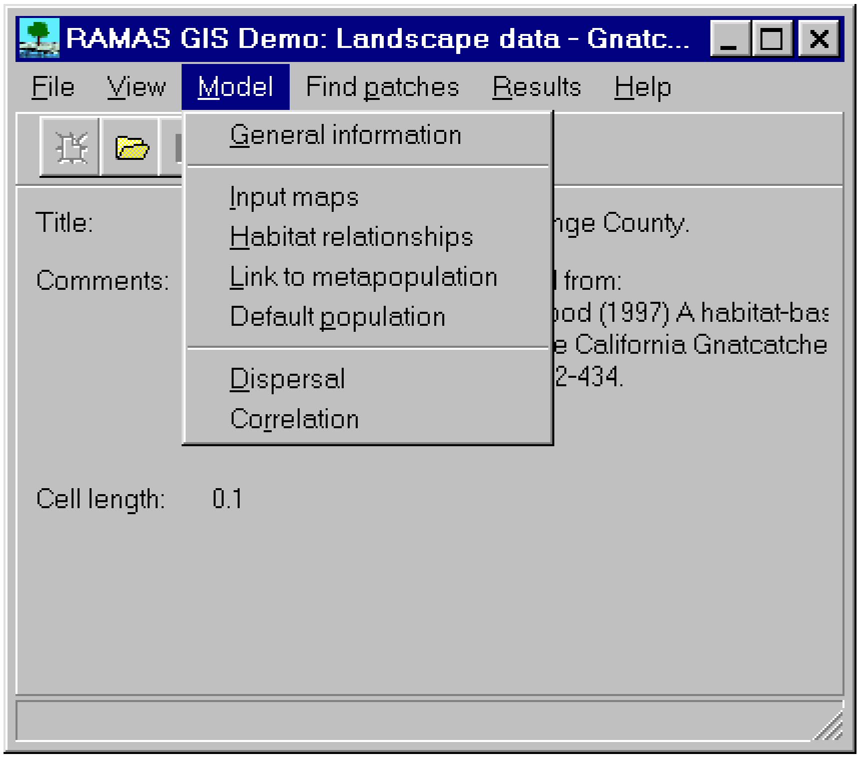
3. Select *Input maps* under the *Model* menu to examine the spatial data incorporated into this file. As shown in the screen shot below there are four coverages considered for the habitat suitability analysis for the gnatcatcher:



If you select *View* from this screen, you will see the map associated with each data set.

4. To view other parameters and functions associated with the spatial data select one of the options in the Model menu such as:

- general information
- input maps
- habitat relationships
- link to metapopulation
- default population
- dispersal
- correlation



5. Select *Run* under the *Find patches* menu. The program will examine the input maps and estimate the number of patches and their locations.
6. You may view the resulting patch structure either as

(a) plain map (change to none in the *Draw patches as:* box in the *Options* screen from the *View* menu) or

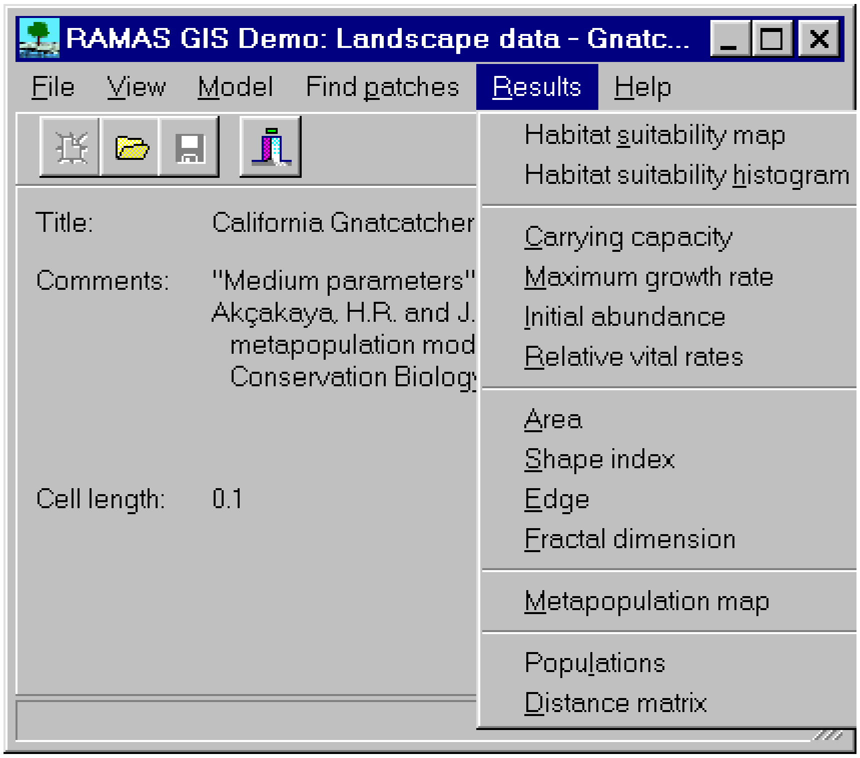
(b) map with patches as polygons (change to polygons in the *Draw patches as:* box in the *Options* screen from the View menu.

Then select *Habitat suitability map* from the *Results* menu.

7. You may view a number of different patch characteristics using the choices in the *Results* menu as shown below.

- habitat suitability map
- habitat suitability histogram
- carrying capacity (K)
- maximum growth rate (Rmax)
- initial abundance
- relative vital rates
- shape index
- edge
- fractal dimension
- metapopulation map
- populations
- distance matrix

- area



8. You may also save the patch spatial structure as a metapopulation map for use with the population model by selecting *Save RAMAS Metapop file* from the *File* menu.

   NOTE: this save feature not enabled in the demo version.

Metapopulation Model

For a demonstration of how different management actions can be compared, you can compare three hypothetical management scenarios:

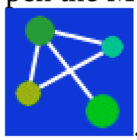
1. No Action: in this file the parameters are based on field data (see reference) with no modifications for management.

2. Higher Fecundity: in this file the parameters reflect an increase of 25% in all fecundity values to mimic the effects of removing nest parasites (such as cowbirds) and other management strategies that might increase breeding success.

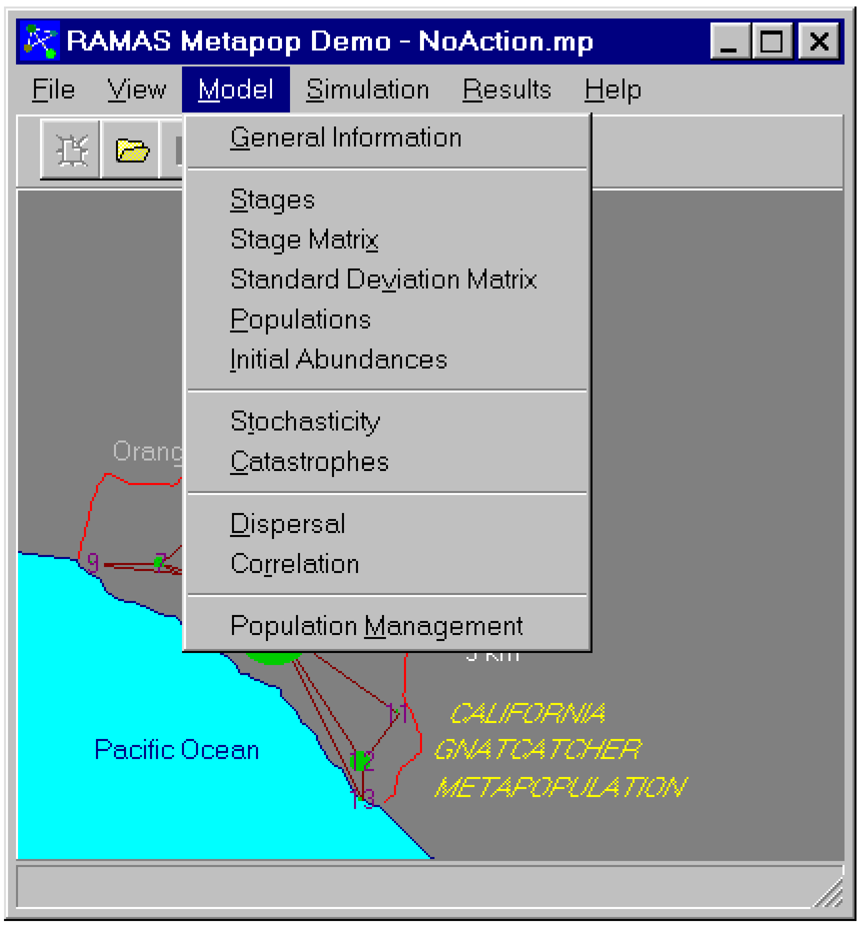
3. Larger K: in this file the parameters reflect an increase of 25% in the carrying capacity (i.e., the maximum number of individuals that can be sustainably supported by the habitat available) to mimic the effects of restoration of habitat or other management strategies that

might increase the amount of available habitat.

NoAction

1. Open the Metapopulation model program by clicking on the icon .
2. Begin by examining the model with baseline parameters and no management action. Select *Open* from the *File* menu and choose NoAction.mp.

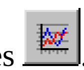
3. The specific values for parameters may be examined through the *Model* menu (shown below).



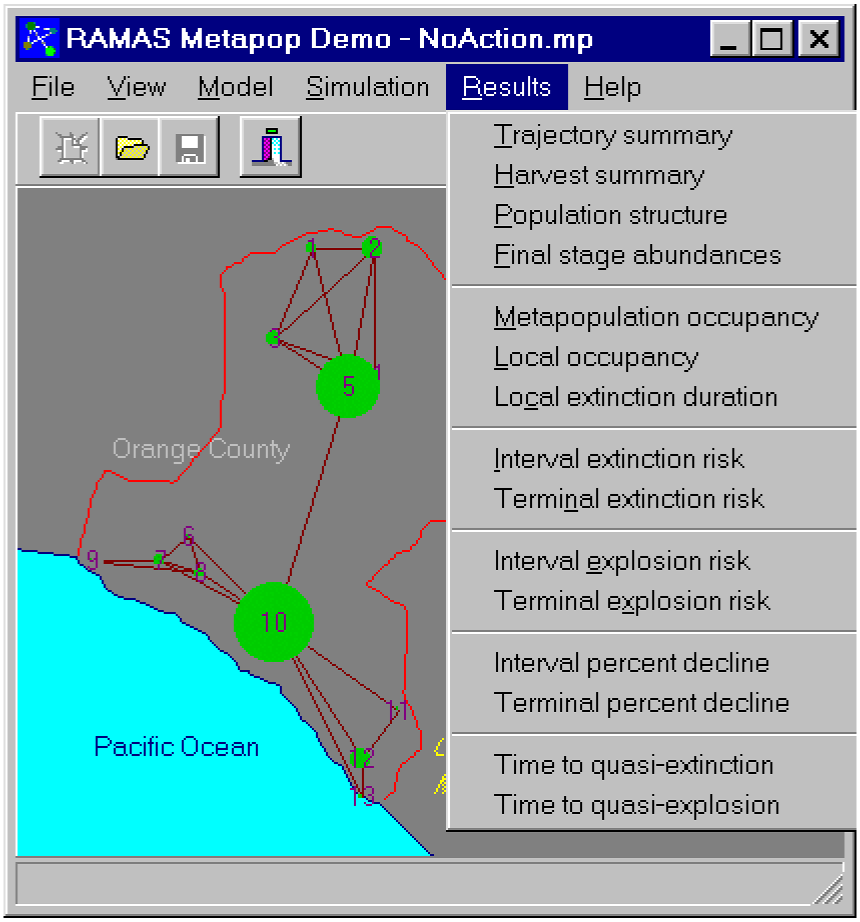
These parameters include:

- stages: names and weights of each life-history stage in model
- stage matrix: transition matrix of survival and fecundity values

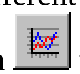
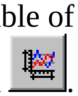
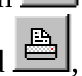
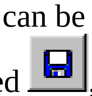
- standard deviation matrix: annual variation in transition values
- populations: population-specific parameters
- initial abundances: starting size for each population
- stochasticity: specific characteristics of the type of variation
- catastrophes: parameters for each catastrophe
- dispersal: matrix of dispersal rates among populations
- correlation: matrix of annual correlation of vital rates among populations
- population management: parameters for harvest, introduction or translocation

4. Select *Run* from the *Simulation* menu to begin running the replications. A new window will open and the simulation will begin. You may view the replications as text  (fastest option) or as a dynamic map  or as trajectories .
5. When the simulation is complete you may view the results in a number of different ways (as shown below) from the choices in the *Results* menu.

- trajectory summary
- harvest summary
- population structure
- final stage abundance
- metapopulation occupancy
- local occupancy
- local extinction duration
- interval extinction risk
- terminal extinction risk
- interval explosion risk
- terminal explosion risk
- interval percent decline
- terminal percent decline
- time to quasi-extinction
- time to quasi-explosion



6. Each of the results may be viewed in different ways:

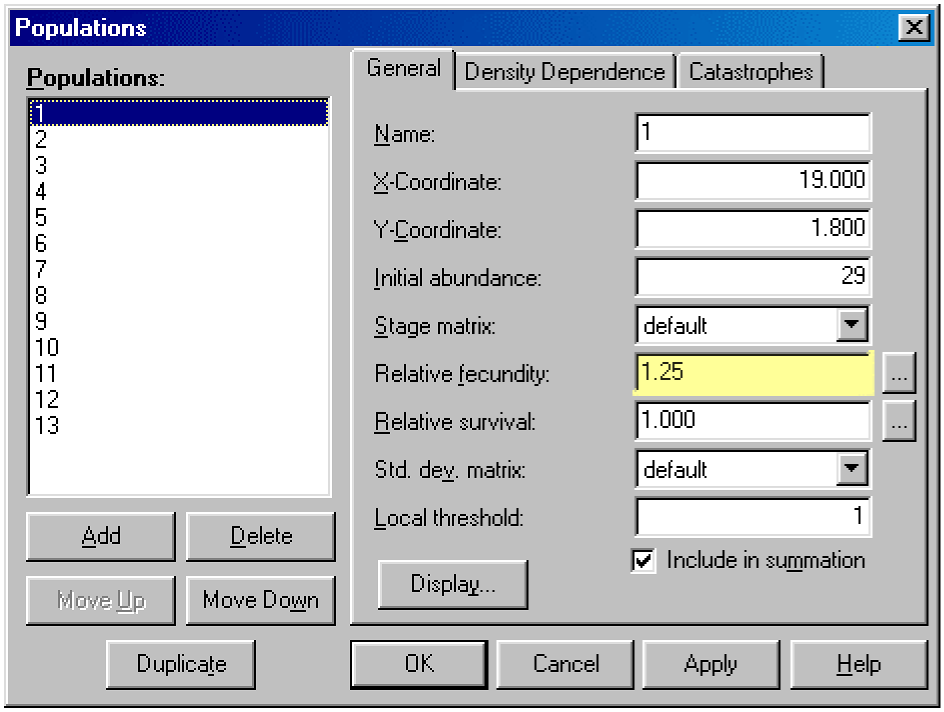
as a table of numbers  or as a graph  that can be scaled . The results may be printed , saved , or copied to the clipboard .

HighFecundity

1. Select *Open* from the *File* menu and choose HighFecundity.mp.

2. As before, examine the various parameters of the model compared to the NoAction model through the *Model* menu choices.

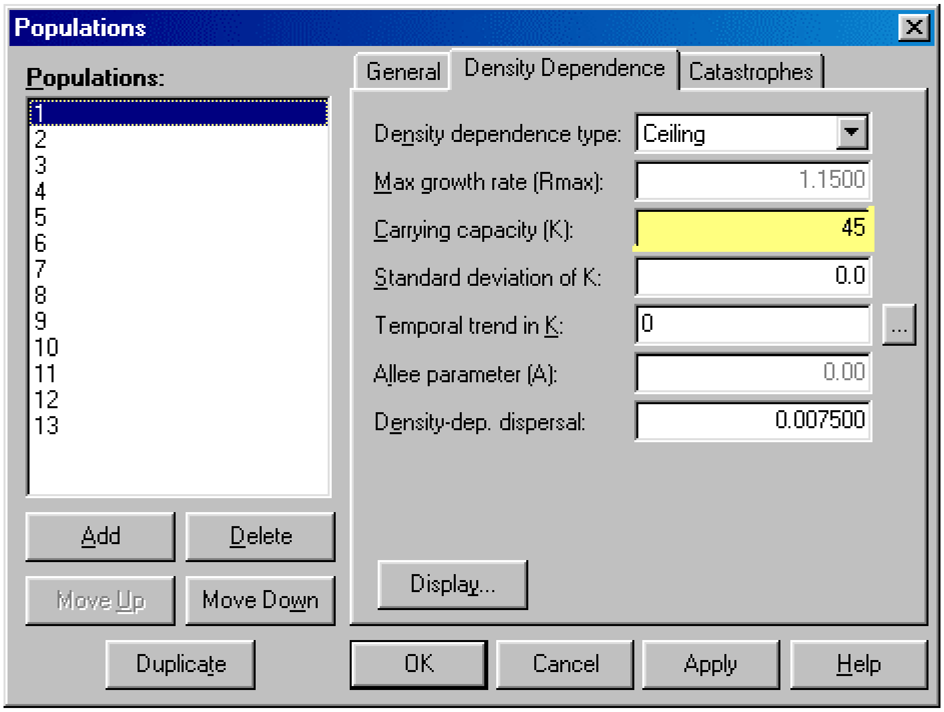
3. Select *Populations* from the *Model* menu. Note that for this file the *Relative fecundity* for each population has been increased by 25%. (see picture below)



4. Select *Run* from the *Simulation* menu and observe the change(s) that increasing the fecundity makes on the population trajectories.
5. View the results from the *Results* menu as above.

LargerK

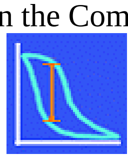
1. Select *Open* from the *File* menu and choose LargerK.mp.
2. As before, examine the various parameters of the model compared to the NoAction model through the *Model* menu choices.
3. Select *Populations* from the *Model* menu. Note that for this file under the *Density Dependence* tab, the *Carrying capacity (K):* box has a value 25% larger for each population than in the NoAction file.

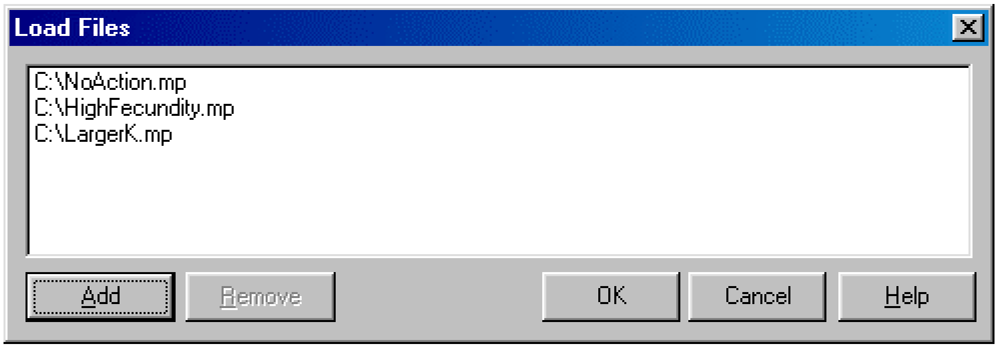


4. Select *Run* from the *Simulation* menu and observe the change(s) that increasing the capacity makes on the population trajectories.
5. View the results from the *Results* menu as above.

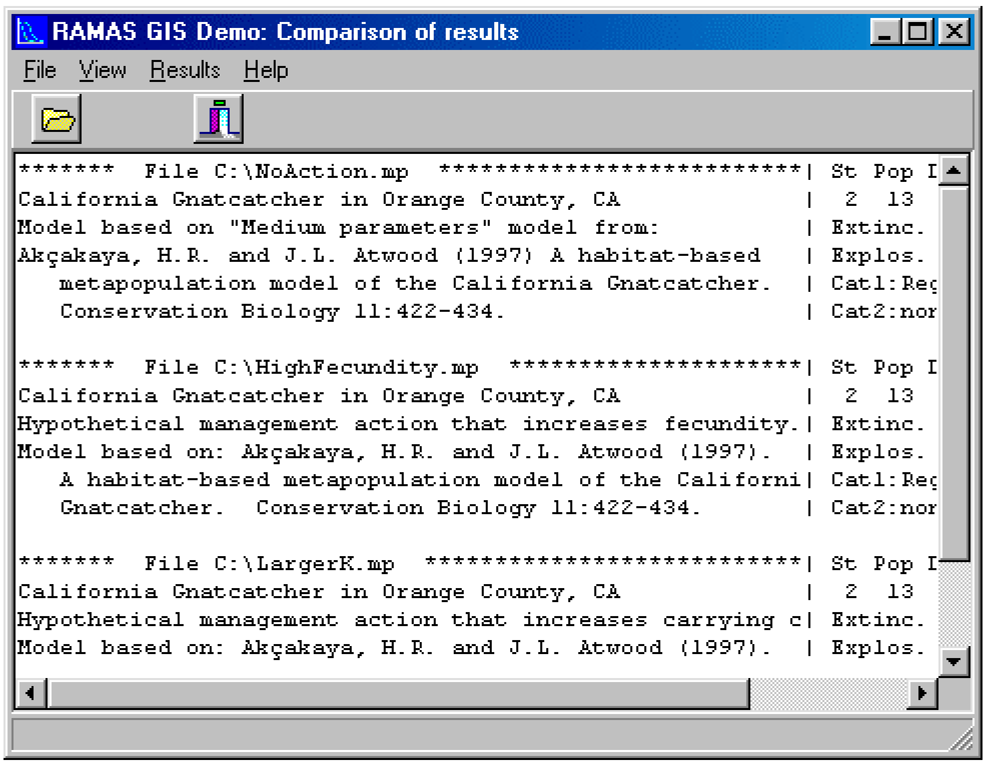
Comparison of Results

You may also directly compare the results of the three management strategies by using the Comparison of Results program.

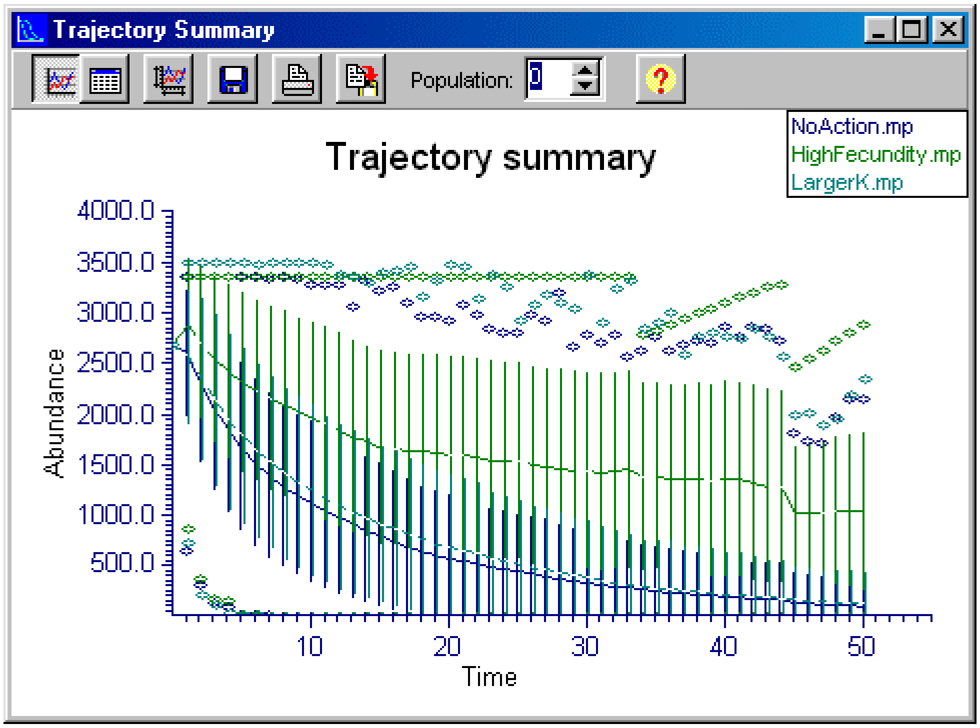
1. Open the Comparison of Results program by clicking on the icon .
2. Select Load files... from the File menu. Click the Add button and select each of the three files with results: NoAction, HighFecundity, LargerK.



3. Once you have added the files click OK and the main program window should show a text description of the selected files.



4. View the results from the *Results* menu as above. Each of the files will appear as a different colored set of lines on the graphs.



See above for viewing options.

ETS05
Appendix VIII
Correspondence between IUCN and USFWS Classifications of Threatened Species

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BIOMATHEMATICS®

Correspondence between IUCN and USFWS classifications of threatened species

3.2.6a Background and objectives

The Endangered Species Act (ESA) was implemented in 1973 to prevent extinction of animals and plants through the protection of their ecosystems and the development of specific conservation programs (USFWS 1998). The ESA authorizes officials to categorize species facing risk of extinction as either endangered or threatened based on the magnitude of extinction risk. Federal agencies are then obligated to carry out conservation measures to protect these species by imposing regulations to preserve critical habitat or to restrict harvesting levels as deemed essential for their conservation.

Assessing the extinction risk of species is imperative for implementing effective conservation strategies and for apportioning limited financial and human resources for species conservation. The determination to list a species as endangered or threatened is, therefore, one of the most critical steps for reaching the objectives of the ESA. Yet, the protocol for prioritizing taxa for protection has been criticized by some in the scientific community as being arbitrary because there are no explicit guidelines by which these decisions are made (General Accounting Office 1979, Sidle 1990, Easter-Pilcher 1996). The use of biological criteria in the decision making process is inconsistent and descriptive variables often receive more consideration than quantitative variables (Easter-Pilcher 1996).

In a recent analysis (Easter-Pilcher 1996), ranges of quantitative data represented by qualitative descriptions used in final listing reports were compared. In most cases, distinctly different qualitative descriptions had overlapping or analogous numerical ranges. For example, in final listing reports made between 1975 and 1991, species given the qualitative description "rare" ranged from 30 to 12,500 individuals and species described as "extremely rare" ranged from 14 to 7000 individuals. In the same study, a discriminate function model was unable to adequately discriminate threatened and endangered species given the data used in the final listing reports. No threshold values exist in the process that separate endangered species from threatened species.

The system for listing endangered and threatened species was made flexible "so that important biological considerations that fall outside the scope of consideration of the system can figure into particular decisions on an *ad hoc* basis" (USFWS 1983). This flexible system has not only made listing decisions inconsistent but has also made it easy for officials to ignore ESA policy which requires them to disregard political issues and to base listing decisions on the best scientific data available. One example is the recent decision not to list the Canada lynx (*Lynx canadensis*) in the United States *(Defenders of Wildlife et al. v. Babbit et al*. 1997). The Department of the Interior and politically appointed USFWS officials allowed politics to influence the listing process. They decided not to list the lynx despite the agreement among all USFWS biologists who were considering the issue, that the lynx should be listed. The federal court concluded that this decision was "arbitrary and capricious" and against legal standards.

Although the USFWS has acknowledged that "no more time than is necessary should be devoted to the assigning of priorities" (USFWS 1983), the listing process is slow and statutory deadlines are often missed. There is presently a backlog of candidate species waiting listing decisions. Often, by the time species are listed, their prospects for recovery are low, which may explain the poor success rate met by species' recovery plans (General Accounting Office 1993, General Accounting Office 1988, Wilcove 1995).

Development of a system that utilizes explicit guidelines and quantitative data may be useful for avoiding the problems discussed above and would result in a greater consistency in listing decisions. While it may be best to categorize species according extinction risk by doing a formal population viability analysis, data on most taxa are very limited, making such analyses impossible. The use of a structured decision making system that uses objective and quantitative criteria relating to extinction risk may be the next best alternative in these cases.

One system used for classifying species according to estimated extinction risk has received wide acceptance from the international community and has been hailed by the National Research Council (1995) as the "most important scientific effort to date to reach consensus on standard criteria for assigning taxa to threat categories in a uniform, objective manner." This system was developed by the World Conservation Union (IUCN, formerly known as the International Union for the Conservation of Nature), the principal international organization involved with listing species threatened with extinction. In addition, software is now available that allows users to input available data on probability of extinction, trends in abundance, population size, and extent of occurrence to classify species according to IUCN standards, even in the face of uncertainty. This allows efficient, non-biased, scientifically based classification of species of concern.

Despite criticisms of the USFWS listing protocol, few quantitative or systematic analyses of the system have been conducted (but see Wilcove *et al.* 1993 and Easter-Pilcher 1996). In this study, the USFWS listing protocol is evaluated by comparison with the IUCN system. Risk classifications of sixty species were examined under both the USFWS and the IUCN systems and compared. Before continuing with this discussion, some knowledge of the IUCN and USFWS listing processes may be useful. A summary of the listing criteria and categories for the IUCN and USFWS are presented in Tables 1 and 2.

IUCN Listing Process

A specialist group exists for each taxonomic group under the IUCN. Each specialist group is responsible for classifying species that fall under the group's specialization according to level of extinction threat. Species that satisfy one of five criteria based on thresholds of population size, trend, distribution, and extinction probability (A-E; Table 1) are classified into one of IUCN's three threatened categories (Critically endangered, Endangered, or Vulnerable). Species that do not meet these criteria are given the status, Lower risk. Threshold ranges of quantitative variables within each of the five criteria separate each category of endangerment. In all, 12 quantitative variables are examined for each species under this system. If all relevant data are not available, as is often the case, a species may still be evaluated under this system because of the many variables examined.

USFWS Listing Process

The Secretary of the Interior acts through USFWS to carry out the listing process. Species, subspecies, or distinct vertebrate populations become candidates for listing by suggestion of the Secretary or by a petition from a concerned party or individual. The ESA allows 90 days for review of supporting documentation to make a listing decision

Table 1. Summary of IUCN Categories and Criteria (from IUCN 1994).

	Critically Endangered	Endangered	Vulnerable
A. Declining Population			
population decline rate in 10 years or 3 generations of at least	80%	50%	20%
using either:			
1. population reduction observed, estimated, inferred, or suspected in the past or			
2. population decline projected or suspected in the future based on:			
a. direct observation			
b. an index of abundance appropriate for the taxon			
c. a decline in area of occupancy, extent of occurrence and/or quality of habitat			
d. actual or potential levels of exploitation			
e. the effects of introduced taxa, hybridization, pathogens, pollutants, competitors, or parasites			
B. Small Distribution and Decline or Fluctuation			
Either extent of occurrence, or	<100km^2	<5,000km^2	<20,000km^2
area of occupancy	<10km2	<500km2	<2000km2
and 2 or the following 3:			
1. either severely fragmented (isolated subpopulations with a reduced probability of recolonization, if once extinct) or known to exist at a number of locations	1	$\leq$5	$\leq$10
2. continuing decline in any of the following:			
a. extent of occurrence			
b. area of occupancy			
c. area of occupancy			
d. number of locations			
e. number of mature individuals			
3. fluctuating in any of the following	>1 order of magnitude	>1 order of magnitude	>1 order of magnitude
a. extent of occurrence			
b. area of occupancy			
c. number of locations or subpopulations			
d. number of mature individuals			
C. Small Population Size and Decline			
Number of mature individuals	<250	<2,500	<10,000
and one of the following 2:			
1. continuing decline at a rate of	25% in 3 years or 1 generation	20% in 5 years or 2 gen.	10% in 10 yrs or 3 gen.
2. continuing decline and either			
a. fragmented with all subpopulations	<50	<250	<1,000
b. all individuals in a single subpopulation			
D. Very Small or Restricted			
either			
1. number of mature individuals	<50	<250	<5
2. area of occupancy	N/A	N/A	<100km^2
or number of locations	N/A	N/A	<5
E. Quantitative Analysis			
probability of extinction in the wild is at least	50% in 10 yrs or 3 gen.	20% in 20 yrs or 5 gen.	10% in 100 yrs

Table 2. Summary of USFWS Criteria and Categories (USFWS 1994, 1998)

Taxa qualify for listing if they meet one of the following criteria:

1. Present or expected future loss of habitat
2. Overharvested or overutilized for commercial recreation, scientific, or educational purposes
3. Declining as a result of disease or predation
4. Not adequately protected by present laws and regulations
5. Negatively affected by other natural or human-caused factors

Species meeting the above criteria are then prioritized for listing by the rating system below:

Magnitude of Threat	Immediacy of Threat	Taxonomic Uniqueness	Priority
High	Imminent	Monotypic genus	1
High	Imminent	Species	2
High	Imminent	Subspecies	3
High	Non-imminent	Monotypic genus	4
High	Non-imminent	Species	5
High	Non-imminent	Subspecies	6
Moderate to low	Imminent	Monotypic genus	7
Moderate to low	Imminent	Species	8
Moderate to low	Imminent	Subspecies	9
Moderate to low	Non-imminent	Monotypic genus	10
Moderate to low	Non-imminent	Species	11
Moderate to low	Non-imminent	Subspecies	12

Categories of Endangerment

Endangered taxon- Species, subspecies, or distinct vertebrate population in danger of extinction throughout all or in a significant part of its range.

Threatened taxon- Species, subspecies, or distinct vertebrate population likely to become endangered throughout all or in a significant part of its range.

(often, it takes longer). Taxa qualify for listing if their populations meet one of five criteria: (1) face present or expected future loss of habitat; (2) are overharvested or overutilized for commercial, recreational, scientific, or educational purposes; (3) are declining as a result of disease or predation; (4) are not adequately protected by present laws and regulations, and/or (5) are negatively affected by other natural or anthropogenic factors (USFWS 1988). These criteria are not explicit and answers are easily subject to human biases.

Species determined to meet one or more of these criteria are then prioritized for listing using a system developed to identify plants or animals in the greatest need of protection. Species are ranked on a scale of 1 to 12 based on magnitude of threat, immediacy of threat, and taxonomic distinctiveness (Table 2). There are no clear guidelines or threshold values for deciding the magnitude or immediacy of threat. The final decision to list a species is made by the Secretary of the Interior. Taxa to be protected under the act are listed as either *Endangered* or *Threatened* based on the level of perceived extinction risk. An endangered species is defined as being "in danger of extinction throughout all or in a significant part of its range" and a threatened species is "likely to become endangered throughout all or a significant part of its range" (USFWS 1988). No quantitative criteria are required for this process, and no thresholds exist to separate the categories of endangerment.

Methods

Species listed as endangered or threatened under the Endangered Species Act are ranked according to "degree of threat" under the recovery priority ranking system (USFWS 1988). Each species is determined to face either a low, moderate, or high degree of threat. The definitions given for endangered and threatened species imply that endangered species face a higher degree of threat than threatened species. This assumption was tested by comparing the endangerment listing with the degree of threat, reported in the recovery priority listing (USFWS 1999), of 36 federally listed species of California.

Sixty animal species native to California were classified according to criteria from the International Union for Conservation of Nature and Natural Resources (IUCN) and the United States Fish and Wildlife Service (USFWS), see Table 3, as of April 1999. The degree of correspondence between the classification systems was then examined. IUCN classifies each species into one of four categories (Critically endangered, Endangered, Vulnerable, and Lower risk) based on ecological variables such as number of mature individuals, recent declines, geographic distribution and extinction risk. USFWS classifies species at risk into one of two categories (endangered and threatened) based on magnitude and immediacy of threat and taxonomic uniqueness.

If a species was previously evaluated by IUCN, its status was taken from IUCN (1996). Species chosen that were not already listed by the IUCN (1996) were classified according to the IUCN criteria. Information concerning the populations of each species and their habitat was collated from the scientific literature and from USFWS status reports. This information was then incorporated into RAMAS RedList (Applied Biomathematics, Setauket, NY), a program that uses numerical thresholds of ecological variables to classify species according to IUCN criteria (Akçakaya and Ferson 1999). For more information on this program see the web site at http://www.ramas.com. Twenty-four of these species were not listed by the USFWS (USFWS 1999) and could not be evaluated confidently for comparison because the USFWS criteria for listing species are not explicit.

The correspondence was examined between the IUCN and the USFWS classifications. It was assumed that IUCN's lower risk category corresponds to the species not listed by the USFWS. The highest ranked categories of IUCN, (critically endangered and endangered) were assumed to correspond to the USFWS category endangered. Because there are fewer categories under the USFWS system, it was also assumed that threatened corresponds to both endangered and vulnerable categories of the IUCN. The degree of disagreement between classification systems was determined from the proportion of species that did not fall within the corresponding categories.

Table 3. Classifications of 60 species of California (as of April 1999).

Scientific Name	Common Name	Federal Status	IUCN Status
Mammals			
Ammospermophilus nelsoni	Nelson's Antelope Squirrel	Not Listed	Endangered
Aplodontia rufanigra	Point Arena Mountain Beaver	Endangered	Vulnerable
**Canis latrans*	Coyote	Not Listed	Lower Risk
Dipodomys heermanni morroensis	Morro Bay Kangaroo Rat	Endangered	Critical
Dipodomys ingens	Giant Kangaroo Rat	Endangered	Critical
**Dipodomys merriami parvus*	San Bernadino Merriam's Kangaroo Rat	Endangered	Endangered
Dipodomys nitratoides exilis	Fresno Kangaroo Rat	Endangered	Critical
Dipodomys nitratoides nitratoides	Tipton Kangaroo Rat	Endangered	Critical
**Dipodomys stephensi*	Stephens' Kangaroo Rat	Endangered	Endangered
Gambelia silus	Blunt-nosed Leopard Lizard	Endangered	Endangered
Microtus californicus scirpensis	Armagosa Vole	Endangered	Critical
**Ovis canadensis californiana*[a]	Seirra Nevada Bighorn Sheep	Candidate	Endangered
**Ovis canadensis cremnobates*	Peninsular Desert Bighorn Sheep	Endangered	Endangered
Perognathus longimembris pacificus	Pacific Pocket Mouse	Endangered	Critical
Reithrodontomys raviventris	Salt Marsh Harvest Mouse	Endangered	Vulnerable
Spermophilus mohavensis	Mohave Ground Squirrel	Not Listed	Vulnerable
Urocyon littoralis	Island Grey Fox	Not Listed	Lower Risk
**Vulpes macrotis mutica*	San Joaquin Kit Fox	Endangered	Vulnerable
Birds			
Amphispiza belli clementeae	San Clemente Sage Sparrow	Threatened	Vulnerable
Aquila chrysaetos	Golden Eagle	Not Listed	Lower Risk
Buteo swainsoni	Swainson's Hawk	Not Listed	Lower Risk
Campyloryhnchus brunneicapillus	Cactus Wren	Not Listed	Lower Risk
Empidonax traillii extimus	Southwestern Willow Flycatcher	Endangered	Endangered
Eremophila alpestris actia	California Horned Lark	Not Listed	Lower Risk
Falco peregrinus anatum[b]	American Peregrine Falcon	Endangered	Lower Risk
Gymnogyps californianus	California Condor	Endangered	Critical
Haliaeetus leucocephalus[b]	Bald Eagle	Threatened	Lower Risk
Lanius ludovicianus mearnsi	San Clemente Loggerhead Shrike	Endangered	Critical
Pipilo crissalis eremophilus	Inyo California Towhee	Threatened	Critical
Polioptila californica californica	Coastal California Gnatcatcher	Threatened	Endangered
Rallus Longirostris obsoletus	California Clapper Rail	Endangered	Endangered
Strix occidentalis caurina	Northern Spotted Owl	Threatened	Lower Risk
Vireo bellii pusillus	Least Bell's Vireo	Endangered	Endangered
Reptiles			
**Gopherus agassizii*	Desert Tortoise	Threatened	Vulnerable
Thamnophis gigas	Giant Garter Snake	Threatened	Vulnerable
**Thamnophis sirtalis tetrataenia*	San Francisco Garter Snake	Endangered	Endangered
**Uma inornata*	Coachella Valley Fringe-toed Lizard	Threatened	Endangered
Xantusia riversiana	Island Night Lizard	Threatened	Vulnerable
Amphibians			
Bufo exsul	Black Toad	Not Listed	Vulnerable
Rana cascadae	Cascades Frog	Not Listed	Vulnerable
Batrachoseps aridus	Desert Slender Salamander	Endangered	Critical
Batrachoseps stebbinsi	Tehachapi Slender Salamander	Not Listed	Vulnerable

Table 3. (continued)

Scientific Name	**Common Name**	**Federal Status**	**IUCN Status**
Batrachoseps simatus	Kern Canyon Slender Salamander	Not Listed	Vulnerable
Hydromantes shastae	Shasta Salamander	Not Listed	Vulnerable
Hydromantes brunus	Limestone Salamander	Not Listed	Vulnerable
Fish			
Chasmistes brevirostris	Shortnose Sucker	Endangered	Endangered
Cyprinodon radiosus	Owens Pup Fish	Endangered	Endangered
Deltistes luxatus	Lost River Sucker	Endangered	Endangered
Gila elegans	Bony Tail Chub	Endangered	Endangered
Hypomesus transpocificus	Delta Smelt	Threatened	Endangered
Gastropods			
Helminthoglypta walderiana	Morro Shoulder Band Snail	Endangered	Critical
Monadenia setosa	Trinity Bristle Snail	Not Listed	Vulnerable
Crustaceans			
Branchinecta conservatio	Conservancy Fairy Shrimp	Endangered	Endangered
Branchinecta longiantenna	Longhorn Fairy Shrimp	Endangered	Endangered
Branchinecta lynchi	Vernal Pool Fairy Shrimp	Threatened	Vulnerable
Branchinecta sandiegoensis	San Diego Fairy Shrimp	Endangered	Endangered
Streptocephalus woottoni	Riverside Fairy Shrimp	Endangered	Endangered
Insects			
Desmocerus californicus dimorphus	Valley Elderberry Longhorn Beetle	Threatened	Lower Risk
Elaphrus viridis	Delta Green Ground Beetle	Threatened	Critical
Polyphylla barbata	Mount Herman June Beetle	Endangered	Lower Risk
Trimerotropsis infantilis	Zayante Band-winged Grasshopper	Endangered	Endangered

* indicates species classified with available data using RAMAS RedList
[a] recently proposed for emergency listing
[b] recently proposed for de-listing

Results

A comparison of Table 1 and Table 2 reveals a large degree of correspondence between the criteria used by USFWS and by the IUCN, for details see Table 4. The only USFWS criterion that does not have an explicit counterpart in the IUCN criteria is "Not adequately protected by present laws and regulations" (FWS criterion 4). However, those species that are not adequately protected will have

(1) declining area of occupancy, area, extent and/or quality of habitat, number of locations or subpopulations or mature individuals (IUCN criterion B2), or
(2) continuing decline in numbers of mature individuals, combined with fragmentation (IUCN criterion C2), or
(3) a high risk of extinction (IUCN criterion E).

Thus, although protection by existing laws and regulations is not an explicit part of the IUCN criteria, the effects of the lack of such protection will be reflected in at least three of the criteria.

Table 4. IUCN criteria that correspond to each of the 5 USFWS criteria for listing. For details of each set of criteria, see Table 1 and Table 2.

	IUCN				
FWS	**A**	**B**	**C**	**D**	**E**
1. Present or expected future loss of habitat	A1c A2c	B2c			
2. Overharvested or overutilized for commercial recreation, scientific, or educational purposes	A1d A2d				
3. Declining as a result of disease or predation	A1e A2e		C1 C2		
4. Not adequately protected by present laws and regulations		(B2)	(C2)		(E)
5. Negatively affected by other natural or human-caused factors	A1e A2e	B3	C2a,b	D2	

When the degree of threat, as declared in the USFWS recovery priority listing (as of April 1999) of each species, was compared to the assigned endangerment categories, no clear boundaries existed to separate endangered from threatened taxa (Figure 1). Species listed as endangered were most likely to be rated in the high degree of threat category; however, some species listed as threatened were determined to have a higher degree of threat than some endangered species. All species were rated as facing a high or moderate degree of threat, except for the bald eagle, which was listed as threatened despite its low degree of threat rating. Of the remaining threatened species, 40% were classified under the high degree of threat category and 60% fell under the moderate degree of threat category. Ninety percent of the endangered species were categorized as facing a high degree of threat and 10% as moderate.

The correspondence between the USFWS and the IUCN listing categories were compared for 60 native California species (Table 3). The listing status of 19 (31.7%) did not fit into corresponding categories of the IUCN and the USFWS (Table 4). Eight species were listed in a higher endangerment category by the USFWS while 11 were either not listed (9) or listed in a lower threat category (2) by USFWS. Of the 9 species that were not listed by the USFWS, it is unclear how many have not been evaluated and how many were evaluated but considered to have a low extinction risk. When these species were not considered in the comparison, ten of the remaining 51 species (15.7%) were listed in USFWS and IUCN categories that did not correspond.

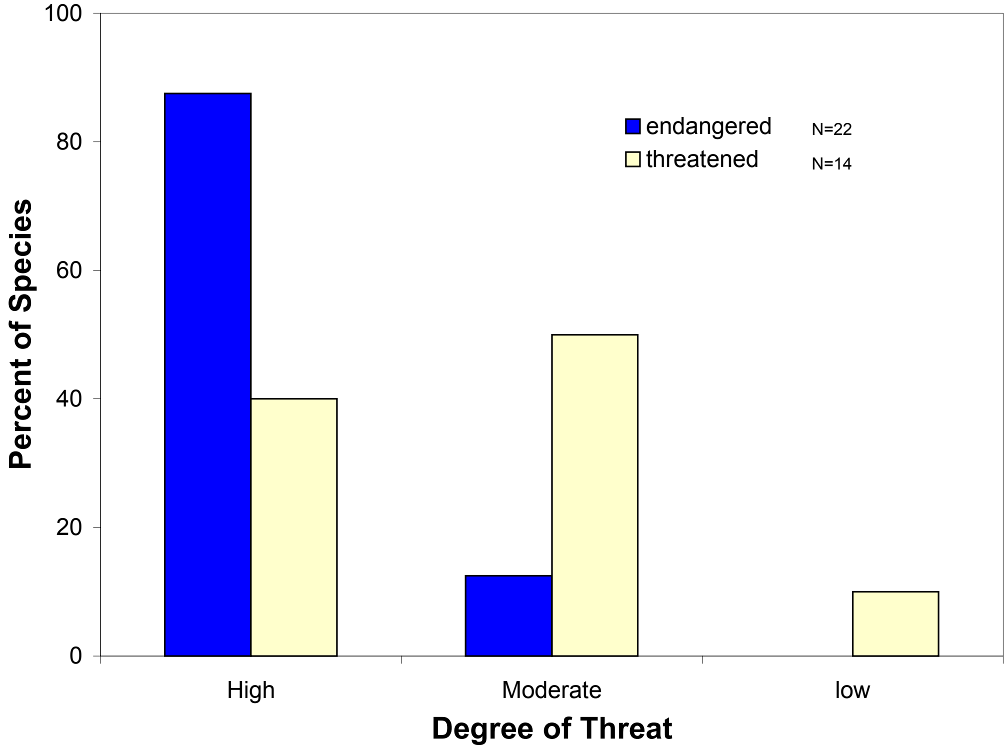

Figure 1. Degree of threat, as rated in the recovery priority listings vs. the USFWS endangerment categories, based on 36 federally listed species of California.

Table 5. Comparison of the listing status of 60 species under IUCN and USFWS. Shaded areas represent corresponding categories.

	IUCN Listing Status				
USFWS Listing Status	**Critically Endangered**	**Endangered**	**Vulnerable**	**Lower Risk**	Total
Endangered	10	17	3	2	32
Threatened	2	3	6	3	14
Not Listed	0	2	7	5	14
Total	12	22	16	10	60

Discussion

The inconsistent use of biological criteria and heavy reliance on qualitative variables by the USFWS result in a low correspondence with the IUCN system and with its own “degree of threat” ranking under the recovery priority listing system. The low correspondence with the IUCN categories was found in spite of the assumption that each USFWS category corresponds to two IUCN categories. Burgman *et al.* (1999) also found low correspondence between the two systems.

Resources for conservation of species are limited. It is, therefore, imperative that decisions are made carefully to focus on species that will receive the most benefit from conservation agents. Also, many species at risk of extinction cannot afford an inefficient listing protocol. These considerations are mentioned in the Endangered Species Act of 1973, yet the present process is both slow and subjective. To revise the federal system, we suggest a new decision making process be developed that is similar in structure to the IUCN system that could easily be modified to satisfy the specifications of the ESA.

The IUCN listing system has several advantages over the USFWS protocol. The IUCN listing process was developed under wide consultation and is recognized internationally by the public and scientific community (National Research Council 1995). The lists of threatened species developed by IUCN are among the most widely used by conservationists around the world. The IUCN criteria were designed to detect risk factors for organisms of widely different taxonomic groups. While all criteria might not be relevant for a particular taxon, there are criteria relevant for assessing extinction threat of all groups (except microorganisms).

When making complex and difficult decisions that are often met with much political resistance, justification is important. The IUCN listing process results in efficient and scientifically defensible decisions. It makes use of explicit guidelines for evaluating different variables that contribute to extinction risk and uses quantitative thresholds to determine degree of endangerment. As a result, decisions are consistent between people and specific reasons for each listing decision are clearly defined. The USFWS listing protocol, however, is ambiguous and subjective.

For most species, data that valuable for evaluating extinction risk are deficient in one or more areas. It may not be possible to gather all relevant data for some species. Data collection may be costly. Or, delaying action to gather all relevant data may place that species in great danger of extinction. The IUCN system accommodates for this problem with the use of multiple criteria. Since meeting any one criterion is sufficient for listing, it is possible to list a species in a high threat category if sufficient data is only available for one criterion.

There is always some uncertainty involved in estimating extinction risk in the form of measurement error, probabilistic predictions, or semantic ambiguity. When this uncertainty is simplified for analysis, it is difficult to prevent human biases from entering the decision making process. One criticism that has been made of the present IUCN system is that it lacks specific rules dealing with the problem of uncertainty (National Research Council 1995). To prevent conflicting management objectives from affecting the decision making process, specific and objective listing protocols that deal with the problem of uncertainty, should be implemented. A new method, allows a user to evaluate species according to the criteria of IUCN while objectively dealing with uncertainty in data (Akçakaya *et al*. 1999; submitted, Ferson *et al*. 1999). Similar software could be developed to meet the objectives of the USFWS listing system.

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Appendix IX
PROCEDURES FOR CREATION AND USE OF ADAR-BASED VEGETATION MAPS TO SUPPORT HABITAT MANAGEMENT

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EXECUTIVE SUMMARY

Airborne Data Acquisition and Registration (ADAR) imagery is a source of high resolution (ca. 1 m), multispectral, digital, georeferenced data that has been proven useful for habitat mapping and monitoring. This research developed operational procedures for mapping several different habitats native to southern California and important to regional, multi-species habitat conservation goals. Procedures leading to the acquisition of ADAR data, creation of ADAR image maps, and data classification to yield habitat maps are documented in a step-by-step manner for their implementation by Southern California Edison's GIAS Laboratory to support Edison's habitat management programs.

The research also developed procedures for the use of ADAR data to detect changes in habitat over time, thus providing a powerful capability that is directly applicable to habitat monitoring and that exceeds the capabilities of conventional habitat mapping methods (in-field mapping on aerial photographic overlays). A qualitative comparison of the relative costs and benefits of using ADAR versus conventional methods finds that ADAR habitat change detection capabilities, along with the wall-to-wall, synoptic character of its digital data, offer significant advantages over traditional mapping methods.

1.0 INTRODUCTION

This report presents results of research to develop methodologies for mapping and monitoring critical California habitats using ADAR (Airborne Data Acquisition and Registration), a high-resolution airborne multi-spectral imaging system. The study is part of a larger research program funded by Southern California Edison and the California Energy Commission to support management of multiple-species habitat preserves in California. Previous reports (Brewster et al. 1997; Stow et al. 1996) described research to establish the feasibility of using ADAR to map coastal sage scrub and saltwater marsh habitats in southern California. This study continues the line of research of the previous investigations and develops procedures to expand ADAR's utility for habitat management purposes. The objectives of the present study are:

- To establish the feasibility of using ADAR to map additional plant community types other than those previously studied.

- To examine the feasibility of using ADAR to detect temporal changes in habitat characteristics.

- To develop a standard set of procedures for the acquisition, processing and classification of ADAR imagery, and to document those procedures for use by Southern California Edison's GIAS Lab.

- To compare the relative costs and benefits of using ADAR with conventional mapping and monitoring methods.

A case study approach was employed to address each of these research goals. Three different study sites were used, each offering a slightly different set of data collection issues and solutions. The feasibility of using ADAR to map previously unstudied plant communities is addressed through two of the study sites: (1) the Hidden Ranch (Black Star Canyon) site in Orange County, and (2) the Etiwanda Alluvial Fan (Deer and Day Canyon Washes) site in San Bernardino County. Detailed descriptions of study sites are given in section 3.0. Both of these study sites offer diverse plant communities: upland oak woodland and chapparal communities in the case of Hidden Ranch, and alluvial fan sage scrub and related communities in the case of Etiwanda. In addition to contributing significantly to the expanding repertoire of habitat types accessible to ADAR, use of these two new sites further confirmed the generalizability of ADAR as a mapping tool to other southern California environments.

A third study site, Sycamore Hills, in coastal Orange County, provided the case study to examine ADAR's ability to track changes in habitat over time. The Sycamore Hills site was the subject of previous feasibility studies to examine ADAR mapping capabilities applied to the coastal sage scrub (and related) plant communities (see Brewster et al., *op.cit*.). The availability of time-series ADAR imagery for Sycamore Hills permitted an analysis of image-to-image differences over time, and the relationship of changes perceived in imagery to on-the-ground changes. The ability to detect temporal changes is essential to the goals of monitoring and managing habitat.

The body of the report documents specific methods used by our research team to accomplish ADAR-based mapping for each of the three study sites. The methods described include several alternative procedures for georeferencing ADAR data, registering multi-date ADAR images, creating a mosaic of multiple ADAR image frames, classifying ADAR data to produce a vegetation map, and using multi-temporal ADAR data to detect changes in habitat. The sum of these procedures provides the capability to create baseline habitat maps in digital, georeferenced form and to monitor habitat changes using ADAR technology. The text gives detailed documentation of procedures executable by SCE's GIAS Lab. Step by step procedures are presented in a distilled form in the Procedures Handbook presented as a separate section of the report (section 12.0).

The use of case studies also allowed us to examine the relative costs and benefits of several alternative methodologies for producing ADAR image maps. These alternatives (section 6.0) include contracting with various outside services to perform post-processing procedures. The report presents findings and recommendations related to these alternatives. Procedures for implementing them are also provided in the Procedures Handbook.

Finally, the report summarizes the relative costs and benefits of using ADAR for mapping and monitoring habitats compared to conventional habitat mapping techniques (section 9.0).

2.0 ADAR AND IMAGE PROCESSING REQUIREMENTS

2.1 The ADAR System 5500

The focus of this study is the Airborne Data Acquisition and Registration (ADAR) System 5500, a commercial, digital multispectral camera system that is built and operated by Positive Systems, Inc. of Whitefish, Montana, USA. ADAR 5500 images are captured directly in digital form with four digital cameras. The CCD array on each digital camera captures an image composed of approximately 1500 x 1000 pixels. The digital cameras are integrated with on-board computers, a global positioning system (GPS), and flight planning and image acquisition software. Softcopy photogrammetry routines are implemented to register individual digital camera frames. Image brightness values are controlled in flight by adjusting the aperture, gain settings and shutter speed of each digital camera. ADAR 5500 image data can be acquired from most fixed-wing aircraft that have some type of aerial camera mount (Stow et al., 1996).

Data obtained with the ADAR 5500 imaging system have several characteristics that make it suitable for detailed and reliable mapping and monitoring of habitat preserves. ADAR data are: (1) digital, (2) multispectral (in visible and near-infrared wavebands), (3) very high resolution, and (4) suitable for geographical reference. When quantitative image analyses are required (e.g., image classification and estimation of biophysical properties), direct digitally captured image data are considered to be a requirement. The ADAR 5500 system used four separate DCS 420 digital cameras, each fitted with a unique absorption filter. Digital imagery is required for flexibility and the ability to view, interpret and map with images "on-screen." Multispectral imagery is needed for discrimination purposes, as land cover types and biophysical conditions are best distinguished and/or quantified by sensing in multiple wavelength bands. Since vegetation and soils are the critical components of habitats, reflected near-infrared radiation provides the greatest amount of information about vegetation types and conditions. To discriminate subtle, yet important features associated with disturbance of habitat and to visually discern vegetation community types, imagery with very high spatial resolution (e.g., 0.2 – 2.0 m) is required. Finally, to co-locate field observation sites and other features that have been surveyed (likely with global positioning systems) and to integrate imagery and image-derived products into GIS databases, images must be geometrically corrected and geographically referenced (i.e., georeferenced) to a given projection and coordinate system. These corrected and georeferenced images are called image maps. For framing systems such as the ADAR System 5500, mosaicking of multiple frames along multiple flightlines is often required. Mosaicking is a time consuming and costly requirement and it is difficult to produce mosaics with consistent image brightness between adjoining frames.

The three processes -- orthorectification, registration and mosaicking -- are generically termed "pre-processing" as they occur before enhancement or classification of imagery begins. They are described in general terms below. Section 6.0 identifies step-by-step procedures for performing them.

2.2 Orthorectification

The process of correcting remotely sensed images for: (1) geometric errors associated with sensor-platform distortions, (2) effects of topographic relief displacement, and (3) projecting and referencing the image to an earth coordinate system (termed "orthorectification.") Even if absolute positional accuracy is not critical to the habitat monitoring effort, mosaicking and achievement of relative positional accuracy between ADAR images captured over time is difficult to achieve without some form of orthorectification.

Several types of approaches can be applied to orthorectify ADAR frames and are described in increasing order of sophistication and cost. Image warping or "rubbersheeting" involves an empirical, polynomial fit based on manually-derived ground control points (GCPs) selected from the raw image and GPS survey or topographic map or orthophotograph (Cook and Pinder, 1996). A more precise and automated approach is based on a softcopy photogrammetric image correlation technique, where portions of individual ADAR frames are matched to an existing digital orthophotograph or georeferenced satellite image. A third approach also involves a softcopy photogrammetric approach applied to framing sensor images, such that stereoscopic pairs are utilized along with knowledge of camera geometry parameters to create a "bundle adjustment." A high resolution digital elevation model is derived from the stereopair or may already exist and is used to correct relief displacement errors. For all of these geometric processing approaches, the transformation from raw image coordinates to a rectified and georeferenced image requires the original image brightness values to be resampled. Effectively, this process is an estimation of what the image brightness values would have been had the sensor sampled the land surface in the manner represented by the corrected image. This resampling process can have significant effects on the results of subsequent image classification and biophysical modeling and should be performed as few times as possible (Dikshit and Roy, 1996).

2.3 Registration

Geometric registration or co-alignment of ADAR image data acquired at different times is one of the processing steps that is most critical to the success of a monitoring program. The relative alignment of time sequential images influences the degree to which actual changes are detected and false changes are minimized. Most of the geometric processing approaches described for orthorectification can be applied to register images spatially, including independent orthorectification of each image. However, the most cost effective solution and the one that often yields the highest registration accuracy, is to use image matching techniques to register subsequent images to a baseline orthorectified image.

2.4 Mosaicking

The need to join multiple digital images to cover a study site is met through the process of image mosaicking. ADAR frames are “stitched” together once they have been orthorectified. Besides the need to extract portions of individual frames and align them to create a single composite image, the generation of a “seamless” mosaic at the join edge often requires a brightness adjustment. Note that this is actually a type of radiometric correction process that is conducted in conjunction with the geometric process of mosaicking. This is normally achieved using an empirical adjustment to modify brightness values in some zone adjacent to the join edge, such that a smoothly varying brightness gradient results. Radiometric correction is the calibration and correction of radiation data provided by the sensor (i.e., adjustment of brightness values).

3.0 STUDY SITES

Figure 1 indicates the regional location of the three study sites. More precise locations and study site boundaries are presented in Figures 2 - 4. The sites were selected for their unique characteristics, described below.

3.1 Sycamore Hills

The Sycamore Hills site is in coastal Orange County, north of the San Joaquin Hills Transportation Corridor (SH 73), between Laguna Canyon Road (SH 33) and El Toro Road. The rugged site includes approximately 206 acres and is vegetated by coastal sage scrub, much of which is dominated by black sage (*Salvia mellifera*); chaparral, consisting mostly of scrub oak (*Quercus berberridifolia* and *Quercus dumosa*) and lemonadeberry (*Rhus integrifolia*); well-developed stands of sycamore (*Platanus racemosa*); and grassland. The site is within the coastal subregion of the County of Orange NCCP (Natural Communities Conservation Plan) and so is of special significance to habitat managers. In addition, the site was selected because of its (1) plant community diversity, (2) relative accessibility, (3) abundance of surrounding urban features to aide in georeferencing, and (4) its familiarity to field biologists of our research team.

Sycamore Hills provided unique challenges and opportunities to the application of ADAR-based mapping methodologies. Its highly variable terrain (and the absence of high quality digital terrain data for the site) necessitated special efforts in georeferencing the ADAR image data. Unlike other sites within the coastal subregion of the NCCP Coastal Sage Scrub preserve, Sycamore Hills is a highly diverse mix of coastal sage scrub types, with no less than 13 subcategories of scrub communities or ecotones. The undulating slopes with variable aspects present conditions in which species composition changes in gradations from one plant community type to another. The site was deliberately chosen for these challenges, with the belief that if ADAR-based mapping proved feasible at Sycamore Hills it is very likely to be feasible at less challenging sites with less complex assemblages of coastal sage scrub.

3.2 Hidden Ranch (Black Star Canyon)

The Hidden Ranch site, also in Orange County, is along the northwest boundary of the Cleveland National Forest on the central coastal slopes of the Santa Ana Mountains. The 807-acre site is approximately five miles north of Santiago Canyon Road, in an unincorporated area of northeast Orange County adjacent to the Riverside County border. Hidden Ranch is within Black Star Canyon, a deeply incised north-south oriented drainage in steep mountainous terrain. Elevations range from 1,070 feet above mean sea level (MSL) in the south to 2,030 feet above MSL in the northeast.

Vegetation at Hidden Ranch is a mosaic of several plant communities (see PCR, 1998). These include several categories of sage scrub communities (sagebrush-buckwheat scrub, white sage scrub, sagebrush scrub, mixed sage scrub, etc.) and chaparral communities (southern mixed chaparral, chamise chaparral, etc.). Both annual grassland and perennial grassland are found onsite, along with woodland communities (coast live oak woodland and sycamore riparian woodland). In addition, several habitats of special interest are found onsite. (For a full discussion of biological resources at Hidden Ranch, see PCR, *op.cit.*).

The presence of scrub and chaparral communities at Hidden Ranch provided a logical extension to earlier ADAR research because of the similarity of these vegetation types to the previously studied Sycamore Hills location. While plant communities at Hidden Ranch are similar at the level of major plant community categories to those at Sycamore Hills, the Hidden Ranch flora represents an assemblage that is characteristic of higher, more inland elevations. It thus provided an added occasion to test the generalizability of the ADAR mapping procedures pioneered previously to an expanded range of communities. Like the Sycamore Hills site, the variable terrain of Hidden Ranch also provided opportunities to explore efficient methods of image georeferencing and registration. Comparative methods are discussed in the case studies section, 5.3.

3.3 Etiwanda Alluvial Fan

The Etiwanda study site is within the alluvial fan system drained by Etiwanda Creek and the Deer Canyon and Day Canyon Washes. The site is north of the City of Rancho Cucamonga in the western portion of San Bernardino County. The alluvial fan and its drainages originate in the mountainous watersheds of the San Bernardino National Forest north of the site. Alluvial fans in this region are historically the site of a distinctive type of shrubland known as alluvial fan sage scrub (AFSS). This plant community is found principally on the alluvial fans on the cismontane sides of the Transverse and Peninsular Ranges of southern California (Barbour and Wirka, 1997). AFSS can vary greatly in species composition from site to site, but is often dominated by scalebroom (*Lepidospartum squamatum*), interior flat-topped buckwheat (*Eriogonum fasciculatum* var. *foliolosum*), California sagebrush (*Artemisia californica*), hairy yerba santa (*Eriodictyon trichocalyx*), chamise (*Adenostoma fasciculatum*), and mountain mahogany (*Cercocarpus betuloides*), among other species. Recent studies describe three seral stages in the AFSS community: pioneer, intermediate, and mature (Smith, 1980). These stages are believed to correspond to relative degrees of disturbance in the flood regime associated with alluvial fan drainages. AFSS is a plant community of special interest not only because of its distinction from other shrubland types, but also because of its increasing rarity. The disappearance of AFSS is attributed to urban development in alluvial fan areas, encroachment of sand and gravel mines, and alteration of the natural hydrology through construction of dams, debris basins and flood control channels (Safford et al., 1998). Because of the plant community's rarity and continued losses, the California Department of Fish and Game has ranked AFSS as a very threatened (Sl.l) natural community (California Natural Diversity Data Base, 1997).

The Etiwanda Alluvial Fan was imaged during an ADAR overflight in December 1998. Elevations at the site range from approximately 1,500 to 2,400 feet above MSL, and the terrain slopes gently in the manner characteristic of a classic alluvial fan formation. Of this area, a smaller subarea (1,844 acres) was selected as a study site. This subarea was chosen for its diversity of vegetation types. In addition to the three phases of AFSS, the study site includes several categories of Riversidian sage scrub, ceanothus chaparral, and several stands of Sycamore and Walnut woodlands. For a full discussion of plant communities at the Etiwanda study site, see the report prepared in association with field mapping for the Etiwanda case study portion of this research (Bramlet, 1999).

4.0 DEFINING MISSION OBJECTIVES

Creating an image-based map for habitat monitoring and management is a complex undertaking and should therefore be planned carefully. A poorly planned mapping exercise, in which mapping objectives and the methods to achieve those objectives are not precisely identified, will very likely result in a product that fails to meet user needs. This is just as true with ADAR-based mapping as with conventional mapping methods, although with ADAR there are additional considerations that require thoughtful planning. For this reason, the first step in the map development process is the identification of specific tasks that will be performed to create the map. The technical procedures in this report are presented in a way that allows them to be applied to a broad range of study sites and habitat monitoring uses. But implementation of these procedures requires decisions related to specific alternatives and parameters. Those decisions should be determined by the objectives of the mapping project and the specific needs of the end-user.

There are three sequential steps to planning a mapping mission: (1) identify mapping objectives, (2) identify methods to achieve objectives, and (3) develop a project plan to implement selected methods.

4.1 Identify Mapping Objectives

Different maps serve different purposes and while some maps are more general in their purposes, others are tailored to a very specific use. The first task in designing a map is to determine the user's need. This may involve assisting the user in clarifying his or her own ideas of the need and the purposes to which the map will be applied. If the user merely says, "I need a veg map," this may indicate a general use map is in order, but it would be well advised to further query the user about what tasks the final map will be asked to perform. In an ideal situation, the map is part of a larger study design with a clearly articulated management objective or research goal. In the absence of a clear mission statement, it is a good practice to interview the user. There may be more than one user, in which case each should be interviewed and their multiple needs articulated to determine if they can be accommodated through a single map.

A useful method for clarifying user needs is to identify desired characteristics of the final map. This can be accomplished by creating a checklist of the map's features and parameters. A partial checklist with examples of feature categories and some selected features and parameters is given below:

Feature Type	Selected Feature/Parameter
Theme or map object	Vegetation
Classification scheme	Westman
Classification scale	Plant community level
Minimum mapping unit	10 sq. meters
Positional precision	5 meters

A definition of mapping objectives should also include determination of the appropriate output format for the final map. If the map is to be shared and exported in a GIS format for integration with other data, compatibility requirements with other systems should be identified early on. Mapping objectives provide input to many of the important ADAR flight parameters, such as spatial resolution or time and date of image acquisition. If the user's objective is to monitor the recurrence of a particular invasive plant species, for example, then the timing of the flight should coincide with the seasonal emergence of that species. In many cases, *a priori* information or a particular hypothesis related to habitat conditions will dictate the selection of final map features.

4.2 Identify Methods

To a large degree, features and characteristics of the desired map will dictate the specific methods used to create the map. For example, if a high degree of positional precision is desired, the preferred method for georeferencing the ADAR image may be with the aid of a digital orthophoto quadrangle (DOQ). But if a DOQ is not available for the site, then perhaps GPS coordinates must be used instead. Selection of methods is thus dependent on the availability of suitable data to support specific procedures. The process of identifying methods may involve research to determine the availability and condition of data. It may also be appropriate to review the relative costs and benefits of contracting with outside service providers to perform specific tasks, such as georectification and mosaicking. Whether the use of such providers makes sense, is of course a project-specific question, and the answer depends on mapping objectives and in-house capabilities.

4.3 Develop a Project Plan

A plan to implement selected methods is a prudent notion. It ensures that tasks are performed in the proper sequence and are properly coordinated. For example, if locational markers are needed on the image for GPS georeferencing purposes, it ensures that placement of markers occurs before the ADAR mission is flown. A project plan can also identify anticipated man-hours for each task and aid overall project management.

5.0 ACQUISITION OF ADAR 5500 IMAGERY

Airborne Data Acquisition and Registration (ADAR) imagery is a commercially available product that is obtained and sold by Positive Systems , Inc., of Whitefish, Montana, USA. The ADAR 5500 system provides broad-band imagery (blue, green, red, and near-infrared) with ground resolution elements (GRE) usually between 0.5 and 3.0 meters. Individual image frame dimensions are 1536 x 1024 picture elements (pixels); therefore, imagery acquired having a GRE of 1.0 meters will cover approximately 1.5 by 1.0 km per frame. ADAR imagery is useful for automated classification, change detection, and visual interpretation since the imagery is digital, multispectral and of high spatial resolution.

Initiating an ADAR acquisition for a study site can be accomplished by contacting Mr. Bruce Burger of Positive Systems, Inc. four to six weeks prior to the acquisition at 406-862-7745 or bburger@possys.com. The following information should be provided to ensure a successful acquisition.

(1) corner coordinates of a study site (regularly or irregularly positioned);
(2) time of day requirements (usually determined by a maximum solar zenith);
(3) desired image endlap and sidelap (often 35% for both);
(4) optimum time period for acquisition (week, month, season, etc.);
(5) spatial resolution.

The optimum acquisition period is usually the time during which ground cover types of interest will be most differentiable in the blue, green, red, and near-infrared (NIR) wavebands. A remote sensing specialist may be consulted to determine the optimum time period of acquisition to achieve data collection objectives. Once provided with the above information, Positive Systems will conduct flight planning so as to meet the user's specifications. Flight planning involves identification of these parameters:

(1) number and positioning of flight lines and image centers;
(2) aircraft altitude and velocity;
(3) camera settings for optimum dynamic range of brightness values;
(4) specific target date for acquisition.

6.0 GENERATION OF ADAR IMAGE MAPS

A wealth of background information and preliminary findings on case studies pertaining to the orthorectification, georeferencing, mosaicking and registration of ADAR image data were provided in the final report of July, 1998 (Brewster et al., 1998). Below is a discussion on options for the generation of ADAR image mosaics and image maps, followed by summaries of procedures and results from several specific efforts at generating image maps for SCE habitat reserve sites. Each case study represents one of many alternative approaches to generating digital image maps.

Southern California Edison has three basic options for converting image frames of ADAR 5500 or other digital multispectral data into image maps: (1) contract one of a handful of third-party, value added service providers, (2) contract Positive Systems, Inc. to perform the processing, or (3) geometrically process the data "in-house" with commercial image processing software.

6.1 Third-party Geometric Image Processing Services

The first option is to have a third-party, commercial provider convert ADAR frames into image maps. Several companies have entered into agreements with Positive Systems, Inc. to provide such services. The contracting and customer interface is handled by Positive Systems, Inc. To date, these companies have included:

Hammon, Jensen and Wallen, Inc. (in Northern California)
ID Vision, Inc. (Florida)
TRIFID Corporation (Missouri)
Vexcel Corporation (Colorado)

(Another company, Tobin International, Inc.(Texas), is a Beta test site for Positive Systems' DIME software and presumably, will become an alternative source for image maps derived from digital frame imagery. e.g., ADAR or scanned air photos). The advantage of the third-party approach is that very sophisticated procedures involving softcopy photogrammetry can be implemented. Such procedures may be required if high georeferencing and/or registration accuracy is to be attained for areas of variable terrain. The main limitation of softcopy photogrammetric approaches is that they can be very expensive. The primary disadvantage of contracting with third-party providers is that turnaround time, attention to customer satisfaction and quality control have been less than desirable. These disadvantages seem to stem from the immature market for very high resolution, multispectral image map products, such that value-added companies do not have a well-developed production model for ADAR and ADAR-type imagery.

Over the course of this study, two particular image map products were contracted from two commercial service providers, each utilizing different geometric processing approaches. An inexpensive product was generated by ID Vision, Inc. of Gainesville, Florida. A more expensive, precision and terrain corrected product was created by Vexcel, Corporation of Denver, Colorado. The contracts were with Positive Systems, Inc. who served as a broker for the geometric processing services.

ID Vision, Inc. created an image map of the Hidden Ranch site by utilizing an image warping approach to register individual ADAR frames to a subset of a US Geological Survey Digital Orthophotographic Quarter Quadrangle (DOQQ). The cost for the image map covering approximately 15 sq. km was around $500, which is exceptionally low. After negotiating the contract and establishing specifications, which took around six months, the product was created by ID Vision, Inc., checked by Positive Systems, Inc. and received by San Diego State University (SDSU) researchers around 2 months later. This initial product had several substantial artifacts and errors including directional transposition and substantial offsets at join boundaries of frames. No header or metadata were included with the image data and thus georeferencing parameters were not available. The initial product was returned to ID Vision. Less than a month later the transposition issue had been corrected and major offsets at frame boundaries were less noticeable except for along a few edges. No reference data were collected or available for assessing positional accuracy. Compared to products generated at SDSU with general purpose image processing routines of the ERDAS Imagine commercial software, the ID Vision product was deemed to have lower positional accuracy and more noticeable image brightness variability across the resultant mosaic. Thus, the

SDSU-generated product was used as the base for the ADAR vegetation map at the Hidden Ranch site instead of the value added product.

A precision, geocorrected image map for a 6 sq. km area of the Superpark that includes the Sycamore Hills reserve was generated by Vexcel, Corporation for $5,000. One reason for requesting this precision product was that no existing digital orthophotographs or other suitable georeferencing base data were available for this study area. Negotiations and contractual arrangements between SDSU, Positive Systems, Inc. and Vexcel took more than a half a year, as did the time for Vexcel to create the product. Our knowledge of the complete process used by Vexcel is incomplete. Apparently, using stock USGS stereo aerial photographs, they generated digital elevation models and digital orthophotographs using softcopy photogrammetric methods applied to digital (scanned) versions of these stereo photographs, and then used the digital orthophotographs as the base for rectification and mosaicking of ADAR image frames. Whether or not the digital elevation model was exploited for orthorectification purposes is unknown to us at this time. Based on 33 independent ground validation points (i.e., not used for generating the image mosaic), the root mean square error (RMSE) of the image map was 11.8 meters. Because this greatly exceeded the contractual tolerance of RMSE = 5 m, we have requested thatVexcel reprocess the ADAR frames to meet the established standard. We are partly encouraged by the fact that for the western half of the image map and for half of the validation points, the RMSE is approximately 3 m and errors appear to be randomly distributed. A linear error trend is readily evident for the eastern half, where positional errors increase linearly to an extreme of almost 30 m at the easternmost end of the image map.

6.2 Image Processing by Positive Systems

In the process of contracting with Positive Systems, Inc. for ADAR image acquisitions, SCE could specify that the final product be an image map. Positive Systems has just begun to provide image mosaics and maps by utilizing their new software product called DIME. The advantages of this option are that DIME is a more sophisticated and rigorous tool for matching image frames to a georeferenced image base (e.g., digital orthophotographs) and both acquisition and geometric processing can be contracted through a single source. Positive Systems developed DIME and their in-house processing service because of past frustrations in failing to find third-party service providers that were reliable, affordable and/or timely. (Note that DIME software will soon be available for purchase and could be implemented at SCE.) Contracting with Positive Systems for image processing may end up being more expensive than SCE employees generating image maps “in-house.”

6.3 Specifications for Image Map Products

Irrespective of which organizational entity performs the geometric processing and which procedures are employed, there are several important variables that SCE will need to consider and then specify to achieve useful image map products. Contracted service providers may not necessarily ask for all of the important variables to be specified, but it is advisable for SCE personnel to specify them. These important variables or considerations for the output image map (with likely choices made by SCE in brackets) are:

- map projection (with projection zone if applicable) [UTM];
- ellipsoid [Clark];
- datum [1983];
- precise upper-left coordinate for the origin of the bounding rectangle [specific to study site];
- equivalent ground dimensions (x and y) of the picture element (pixel) [1 meter];
- resampling routine used for interpolating or estimating digital number values for output grid (based on relationship to input grid) [nearest neighbor];
- ordering of wavebands [band sequential as blue, green, red, and near infrared bands]
- distribution media [compact disk].

6.4 In-House Production of Image Maps

In-house geometric processing, option 3, would require SCE to purchase, be trained to utilize and implement digital image processing software. The advantage is that this software can or will already be utilized for other image processing and analysis functions, including the vegetation mapping and habitat monitoring analyses described in this report. (That is, to implement the mapping and change analysis functions "in-house," SCE would already have the functionality to generate image maps.) Besides the requirement for training or hiring employees with image processing skills, the biggest disadvantage is the limited sophistication of geometric processing routines implemented in general purpose image processing.

The remainder of this section discusses the in-house methods of producing image maps available to SCE using GIS, GPS, DOQQs, and existing image maps. Each method has been applied during the 1998/1999 or the 1997/1998 project year and is addressed separately as a case study. Numbered, step-by-step instructions are given for each method, with explanatory text and additional instruction given as bulleted items. The basic processes (steps) for all case studies are relatively similar, therefore, the detail of accompanying explanation becomes more limited for subsequent case studies after a step has been initially introduced. If a difference does occur, it is noted. Most differences have more to do with the study site characteristics (e.g., site topography) than with the methods themselves. The basic steps used for all in-house methods discussed in this section are demonstrated in flow chart form in Figure 5.

6.4.1 Registration and Mosaicking to a GIS: The Etiwanda Case Study

Site Mapping History and Methods

The Deer-Day Canyon Wash portion of the Etiwanda site was field mapped by consulting biologist Dave Bramlet in February and March, 1999. A detailed discussion of methods employed to field map the Etiwanda site is provided in the report "Alluvial Fan Sage Scrub Mapping in the Deer-Day Canyon Washes, San Bernardino, California" (Bramlet, 1999). Bramlet mapped the site from a color aerial photograph obtained from Rupp Aerial Photography of Corona, California. The scale of the photograph is 1:3600 or 1 inch equals 300 feet**.**

The aerial photograph used to map the Deer-Day site does not exist in digital format. Therefore, we obtained a digital (scanned), orthorectified, but not georeferenced, black and white, 600 dot per inch (dpi) aerial photograph from Airborne Systems, Inc., of Anaheim, California. The black and white aerial photograph was georeferenced to the Cucamonga Peak 7.5 minute quadrangle using the following procedures:

1) Select well-spaced ground control points (GCPs).

- ***View the digital image data to be georeferenced and the 7.5 minute quadrangle simultaneously.***

- ***Select a minimum of six well-spaced points that occur on both the digital image and the 7.5 minute quadrangle***. Due to the nature of 7.5 minute quadrangles, these points will probably be corners of road intersections. A minimum of six points is required for a second-order polynomial (see discussion below). For the Etiwanda site, eight GCPs were used in the transformation.
- The process of converting file coordinates from an image to be registered to a reference image coordinate system, utilizes transformations which employ polynomial equations. The order of the transformation is related to the complexity of the polynomial, the first order polynomial being the simplest to calculate. The first order transformation, also referred to as a linear transformation, corrects for distortion attributed to location and scale variations across the original image. The first order polynomial also corrects for distortion caused by rotation and skew. This transformation is useful for projecting original imagery to a planar map projection or for projecting one planar map to another planar projection. The second order polynomial transformation corrects for those linear distortions mentioned above and for warping, a nonlinear distortion. Second order transformations may be used for large areas, accounting for the Earth's curvature, and to correct for camera lens distortion. The first and second order transformations are the most commonly used while higher orders are reserved for notably distorted imagery.
- The variability of the topography will dictate the transformation order. First order transformations may be used in areas of little or no relief, while second or third order transformations should be applied in areas exhibiting extensive relief. The number of required GCPs increases with transformation order; the minimum required numbers

are 3, 6, and 10 for first, second, and third order transformations, respectively. However, registration precision will improve with more GCPs and at least twice the minimum is recommended for second and third order transformations.

- ***In a software program of choice, place GCPs on the digital image to be georeferenced and save the file.*** These are the file coordinates.

2) ***Determine the map coordinates for points selected on the 7.5 minute quadrangle.***
   - SCE uses UTM NAD83 meters coordinate system, but most UTM coordinates on 7.5 minute quadrangles are in UTM NAD27 meters. Once the coordinates are calculated, they must be converted to NAD83 using a coordinate calculator software package, which are widely available. These are the map coordinates.

3) ***Using the prompts and/or menu selections of the image processing software, enter the map coordinates in a column next to the corresponding file coordinates.***

4) ***Using the image processing software's prompts, perform the transform of the coordinates.***

5) ***If the RMSE (Root Mean Square Error) is too high, adjust the GCPs by moving them slightly, making their location more precise and transform the coordinates again. Save the coordinate files when the RMSE is at an acceptable level.***
   - When georeferencing a photograph to a 7.5 minute quadrangle, expect the RMSE to be fairly high (>10). A RMSE of 10 is acceptable in this case due to the large area covered and the inaccuracies associated with coordinate determination from 7.5 minute quadrangles and the quadrangles themselves.

6) ***Resample the image.***

   - ***Select a resampling method***. (The nearest neighbor technique was applied at the Etiwanda study site.) Three common resampling methods are nearest neighbor, bilinear interpolation, and cubic convolution. The selected method is applied at the same time the registration transformation is performed. The resampling process is designed to associate a value derived from the unregistered image with a pixel in a new position on the output image. Nearest neighbor resampling assigns the value of the closest pixel on the unregistered image to the output image pixel. This approach retains original data values and is recommended when an image is to be registered prior to classification. A disadvantage is that some data values will be dropped while others are duplicated causing a noticeable stair-step effect and areas of exaggerated or diminished contrast. Bilinear interpolation and cubic convolution are averaging techniques which use a moving window passed across the unregistered image to derive new data values for the output image. The bilinear interpolation method uses distance weighted averaging. From the unregistered image, the values in the four-pixel neighborhood (2x2) closest to each retransformed pixel are used. This method results in a visually smoother output image compared to nearest neighbor results and the data values are spatially truer to those of the original unregistered image. Considering the spatial accuracy of its data values, the bilinear interpolation resampling method may be the best for imagery that will be compared from date to date using computer assisted change detection methods. The cubic convolution resampling method uses the pixel values from a 4x4, 16 pixel neighborhood on the unregistered image to derive an averaged value for the output pixel. The pixels farther from each retransformed pixel have exponentially less weight than closer pixels. The mean and standard deviation of the output pixels match the mean and standard deviation of the input pixels more closely than with other resampling methods. Cubic convolution resampling is recommended when the cell size of the data, and the spatial resolution is being changed significantly to match that of another sensor.

- ***Save the resampled image with new file name***.

The georeferenced photograph was plotted at a scale of 1:3,600, which is the same scale that the vegetation was mapped in the field. A UTM NAD83 grid was plotted over the map of the aerial photograph and sent to the field biologist for boundary transfer. The vegetation class boundaries were transferred from the 1:3,600 scale color aerial photograph used to map the site to clear mylar overlying the plot of the orthorectified and georeferenced black and white photograph. The vegetation class boundaries were then digitized in ESRI's ARC/INFO GIS software and assigned class labels. The newly created GIS coverage was georeferenced using six tick marks derived from the grid plotted over the black and white aerial photograph. Figure 6 shows the resulting GIS vegetation map.

ADAR 5500 Image Data

The ADAR 5500 image data for the Etiwanda site was captured December 11, 1998 between 10:45 and 11:25 am PDT. Positive Systems flew five parallel flight lines in a west-east orientation capturing seventy-three total images. The average spatial resolution was the standard one meter per pixel and the side and end overlap was 35%. The December date may have been late in the year for imaging maximum floristic differences. Earlier flight dates were precluded by the timing of project initiation. At Etiwanda, smoggy skies were also a constraint to imaging and influenced the flight date.

Georeferencing and Mosaicking the ADAR Imagery to a GIS coverage

The Etiwanda ADAR data were georeferenced to the GIS vegetation coverage created in the previous step, because a DOQQ was not available for the area and the available georeferenced image data (the 600 dpi black and white aerial photograph) did not provide sufficient spatial resolution to aid georeferencing. The Etiwanda study site is at the base of the San Bernardino mountains and consists of a low, gently rolling surface that gradually slopes to the south-east. Because of the relatively flat surface, terrain displacement due to elevation changes is not a big factor, therefore, the use of a DOQQ or terrain model in the orthorectification/georeferencing process is less important than for more topographically varied sites. Registering imagery to a GIS coverage is not the most spatially accurate method, but given the available base data, it was the best option available. Also, this ensures that the two GIS coverages will be spatially aligned to each other, regardless of their positional accuracy to earth coordinates. The following procedures were used to georeference and mosaic ADAR frames to the Etiwanda GIS coverage.

1) ***Select ADAR frames that cover the study area.***

   · ***Open and view individual frames to determine frame boundaries and select frames that cover the study area.*** Thirteen frames of the 1998 data were required to cover the Etiwanda study area: 25 - 27, 57 - 60, 69 - 71, and 87 - 89.

2) ***Using image processing software, display the source image (unreferenced data) and the destination image (georeferenced, base image).*** If the flight lines were not flown from south to north, the source images should be rotated to make the top of the image north. The Etiwanda ADAR data were captured with an east - west orientation, therefore, the images were rotated either 90° clockwise or counter-clockwise. For the Etiwanda site, the source images were the thirteen ADAR frames and the destination image was the Etiwanda GIS coverage.

3) ***For each frame, select well-spaced GCPs.***

   · ***First, select a GCP in the source image and then locate the same point in the destination image and place a GCP.*** As stated previously, for a second-order transformation, six GCPs are required. Therefore, it is best to divide the image into six equal blocks and try to place at least one GCP in each block, although the spacing of GCPs is dependent on the terrain and the amount of accuracy needed for registration. Due to camera distortion and terrain displacement increasing outward, points that produce the best registration may be harder to find further away from the center of the image. The spacing of GCPs does not have to be equal across the image but a triangulated pattern of GCPs roughly equiangular works well. More open spacing is tolerable in flatter areas while denser spacing may be required in rougher/steeper areas. If the area has steep terrain and a digital elevation model (DEM) is not available for reference, a field visit to the site or to a comparable site can help the user associate actual terrain variability with its appearance on the imagery.

- The best GCPs are usually road intersections and corners of structures. This is especially true when using a GIS coverage as a base rather than another image. A GIS coverage lacks the detail of an aerial photograph or DOQQ, and often the only features that exist on both the source and destination are road intersections and structures.
- Selecting GCPs that co-occur in the overlap areas of adjacent source images will help reduce positional displacement between frames and will improve the final mosaic.
- For each Etiwanda ADAR source frame, 9 - 13 GCPs were used for georeferencing.

4) For each frame, transform the data using a second-order transformation.

5) If the RMSE is too high, adjust the GCPs by moving them slightly, using the GCP editor's interactive feature for guidance, to make their location more precise and transform the coordinates again.

- Because the study site is relatively flat, a RMSE less than 1 should be achievable for all frames.
- When adjusting the GCPs to improve the RMSE, adjust the one with the highest error first and so on. Often, a lower RMSE can be achieved by moving one of the GCPs from its true matching location. Do not move a GCP to a false location to lower the RMSE. If the RMSE of a GCP cannot be lowered sufficiently, either delete or move both corresponding (source and destination) GCPs. Obtaining an acceptable RMSE can be a long, iterative process, and the time it takes to properly georeference each frame can vary dramatically.

- ***Save the GCP file when an RMSE less than 1 has been achieved***.

6) Resample each image.

- ***Select a resampling method.*** The nearest neighbor technique was applied at the Etiwanda study site.
- ***Save resampled image with new file name.***

7) Check the georeferencing of each frame.

- First, display the newly georeferenced image and overlay the GIS coverage. Inspect the image to see how well it lines up with the GIS coverage. If it does not line up, note areas of displacement and return to the previous step. Add or move GCPs in the area of displacment.
- Once the image lines up with the GIS coverage, display previously georeferenced ADAR images that overlap it to see how they line up. Expect some minor

displacement at the edges of the images, because there is more distortion at the edges. If the images do not line up well, determine which image(s) have the most error and repeat step 5.

8) ***Mosaic frames together to generate an image map.***

- ***To improve the appearance of the mosaic, trim some of the overlapping areas from each frame.*** This step is optional and should be performed with a specific purpose in mind, e.g., to delete coverage outside the study area or extraneous areas that exhibit distortion at the edge of the image. Options for specifying specific extents and portions of images include: (1) use of cutlines to specify where breaks occur between the values of two or more overlapping images; (2) use of areas of interest (AOIs) or polygons to limit the extent contribution of individual input images, or (3) a percentage of overlap to be trimmed can be specified. An overlap reduction of 50% was used for the Etiwanda data.

- ***Add the frames to the mosaicking viewer, select a frame overlap method, and combine.*** The appearance of the mosaic can vary depending on the order in which the frames were specified. Experiment with different combinations to find the best spatially and spectrally matched mosaic. Several approaches to joining overlapping images are available (see discussion below) and the best joining method depends on the application of the finished mosaic. For the Etiwanda site, the feathering option was used.
- There are several different types of intersections that can be used to join and overlap images when creating image mosaics. The overlap function specifies the method that will be used to reduce the multiple layers of image data from the overlap portions of the imagery into one layer. Intersections at overlap areas might be made by simply overlapping one image over another and having the pixel values of the top image become the mosaic's data values. This works well when the registration is very good and differences in brightness values along the boundaries between images are not critical or have been radiometrically corrected. Averaging is another kind of intersection option that can be used when registration and radiometric balance are very good. Using the averaging technique, brightness values of the top and bottom pixels are averaged and that value becomes the data value for the overlap area. Intersections that designate the minimum or the maximum values to become the data values for overlap areas are two options that can be used to influence the evenness of radiometric quality across some mosaics. The feathering intersection type uses a distance weighted averaging that weights top and bottom pixels equally at the center line of the overlap and lessens or increases the influence of the top or bottom pixel moving away from the center line in the direction of one image or the other.

Results

The results of the registration and mosaicking process to a GIS coverage were satisfactory. Figure 7 shows the mosaic as a false color composite. Image brightness values were relatively uniform from frame to frame, although there were a few areas along seam boundaries where slight differences could be detected. Image displacement was noticeable along some linear features (e.g., roads), especially at frame seams and in areas where GCPs were infeasible (such as in the quarry area). As expected, the GIS coverage to which the ADAR frames were registered lined up quite well with the newly created ADAR image map. If the site had had larger and more rapid elevation changes the results would have been less accurate and another method would have been advisable.

6.4.2 Registering and Mosaicking with GPS coordinates - Sycamore Hills Case Study

The two-frame ADAR mosaic of Sycamore Hills used for the July 1998 report entitled, "An ADAR Based Habitat Monitoring System" (Brewster et al., 1998), was created using coordinates collected by a differential GPS receiver. Prior to the July 1997 ADAR flights, coordinates for GCPs were collected for the Sycamore Hills site. The following steps detail how to perform a GPS survey for georeferencing imagery.

1) Find potential GCPs on the image to be georeferenced (source image).

- Display each image and search for inherent scene features that are easy to locate in the field, such as road intersections, the juxtaposition of concrete and asphalt, and structures.
- Try to select GCPs that are well-distributed throughout the image, although this can sometimes be difficult. Place GCPs on the image and save the file to be used in the georeferencing process.
- In most "natural" areas, there are portions of the imagery that contain few, if any, inherent and distinct scene features that can be reliably located and used as GCPs. If this is the case, markers, which can be located on the imagery, must be placed in the field prior to the overflight. Large, white plastic garbage bags staked to the ground will work. Place them in the field the day before or the morning of the overflight, collect coordinates for them using GPS, and retrieve the markers from the field as soon as possible. Leave a stake or rebar at the center of the marker if you want to return to the site at a later date.
- As a general rule, collect five or more GCPs for each frame. For a second-order transformation, you will need a minimum of six per image, but remember in areas where the images overlap, a GCP can be used for both images. It is best to collect more GCPs than are needed and use the reserve GCPs to assess the accuracy of the frames or georeferenced mosaic.

- Search for points with known coordinates, i.e., USGS benchmarks within the study site. Recording these points in the field with the GPS will provide a good accuracy assessment of the GPS data.

2) ***Collect GPS coordinates for GCPs using a differential GPS receiver***.
   - Before collecting data, find a reliable base station. Base station data can be purchased from SOKKIA who operates base stations in both San Diego and Orange County. Free base station data can be obtained via the Internet from the Southern California Integrated GPS Network (SCIGN) and from the Continuously Operating Reference Station (CORS). For more information about these data, see the 1998 report, "An ADAR Based Habitat Monitoring System" (Brewster et al., 1998, p. 10 - 11) or visit the Scripps Orbit and Permanent Array Center's (SOPAC) web site (**http://lox.ucsd.edu/).** GPS base station data can be downloaded from this site.
   - Generate image enlargements on a large format ink jet plotter for each frame, marking the GCPs selected in step 1.
   - Locate GCPs in the field and record their location using GPS. Make sure the data collection interval (epoch) and the time spent recording each GCP are sufficient. For the Sycamore Hills study site, an epoch interval of 5 seconds was used, and data were collected for each GCP for a minimum of 1.5 minutes. Depending on the accuracy of the GPS unit and the distance from the base station, more or less time can or should be spent collecting data for each GCP. At Sycamore Hills, a centimeter level GPS processor was used, but given the length of the recording and the technique used, only decimeter level accuracy data were obtained, which is sufficient. More accurate locational data can be obtained by setting up a tripod to hold the GPS unit in a stationary position over the GCP and collecting data for longer periods of time. Consult your GPS manual for more specific information.

3) ***Download and Process the GPS data.***
   - In most cases the base station data must be converted to a format that is compatible with the GPS data collected in the field. Most GPS software packages perform this function.

4) ***Assess the accuracy of the data.***
   - Accuracy of the GPS points can be assessed from RMSE values accompanying the processed GPS data (normally provided as a by-product of data processing), and by testing against points with precisly known coordinates (e.g., benchmarks).

Once the GPS data have been collected and processed, the images can be georeferenced and mosaicked together. The following steps describe this process:

1) ***Display each image and corresponding GCPs.***

- Use the GCP file created previously. Two frames were used in 1998 for the Sycamore Hills study site.

2) ***Manually input coordinates collected with GPS receiver.***

3) ***For each frame, transform the data using a second-order transformation.*** Use a lower order transformation, if there are less than 6 GCPs per frame.

4) ***If the RMSE is too high, adjust the GCPs by moving them slightly to make their location more precise and transform the coordinates again.***
   - The Sycamore Hills study site is quite rugged with varying topography, therefore, achieving a RMSE under the recommended 0.5 is difficult. Very accurate and tightly spaced topographic data would be necessary to get close to this ideal. For a site like Sycamore Hills with steep, varying terrain, aim for an RMSE of under 3.
   - Save the GCP file when an acceptable RMSE has been achieved.

5) ***Resample each image.***
   - Select a resampling method. The nearest neighbor technique was applied at the Sycamore Hills study site.
   - Save resampled image using a new file name.

6) ***Check the georeferencing accuracy of each frame.***
   - Use any reserve GCPs to assess the spatial accuracy of the image. This step can also be performed after the mosaic is completed. The estimated RMS positional error for the 1997 Sycamore Hills (1998 report) mosaic was estimated to be 5.23 meters based on 12 GCPs.

7) ***Mosaic frames together to generate an image map.***
   - To improve the appearance of the mosaic, trim some of the overlapping areas from each frame (see procedures identified in Section 5.4.1).
   - Add the frames to the mosaicking viewer, select a joining method, and combine. For the Sycamore Hills site, the feathering option was used.

Results

Given the elevational changes at the Sycamore Hills site, the RMSE for the mosaic was good. Minor spatial offsets were noticeable on some of the outlying roadways, but none within the study site itself. Part of the image appeared blurry, which was probably due to a slight misregistration. This could be partially corrected by trimming more of the overlap in the mosaic. Radiometrically, there was a minor difference in brightness values along small portions of the seam.

6.4.3 Registration and Mosaicking with a DOQQ - The Hidden Ranch Case Study

Hidden Ranch ADAR 5500 Images

The image data used to create an image map for the Hidden Ranch site were acquired June 24, 1998 between 12:42 and 12:53 pm PDST. Frame size is the standard 1000 x 1500 pixels with a spatial resolution of one meter per pixel. Nine frames were used for the image mosaic which covered all of township 4 south and range 7 west, section 19 and part of section 25 of the Black Star Canyon 7.5 minute quadrangle.

Image to Image Registration and Mosaicking

Each of the ADAR image frames that covered the Hidden Ranch study site was individually registered to a panchromatic digital orthophoto provided by ID Vision. This orthophoto came georeferenced to UTM projection coordinates. To begin the registration process, evenly distributed ground control points (GCPs) were selected from natural and manmade features recognizable on the reference orthophoto and the ADAR images. After selecting GCPs the second-order polynomial transformation and nearest neighbor resampling method were used to register each image to the orthophoto. The bilinear interpolation resampling method was tested and found to be equally suitable. The second order polynomial transformation was chosen for this dataset because it corrects for distortion attributed to location and scale variations across the image, for rotation and skew, and also for warping. Below is a list of steps used to register and mosaic nine ADAR frames to a DOQQ. These procedures are similar to steps identified previously, so many are abbreviated.

1) ***Select ADAR frames that cover the study area***

2) ***Display the source (ADAR) and destination (DOQQ) image(s).***

3) ***For each ADAR frame, select well-spaced GCPs.*** Select at least six GCPs distributed across the image.

4) ***Transform the data using a second-order polynomial.***

5) ***If the RMSE is too high, adjust the GCPs by moving them slightly to make their location more precise and transform the data again.***
   - The terrain at the Hidden Ranch study area is rough and varied, making terrain displacement on the imagery a real problem. Due to the displacement, the best registration results were obtained by keeping the RMSE less than 5.00. Input and reference GCPs were moved or slightly adjusted to improve the RMSE after initial placement. If a GCP could not be moved to within the optimum value, it was changed to a check point or deleted altogether.

- After placement of all GCPs check that input and reference points are still matched pairs, located on the same feature on input and reference image, and that the control point error is as low as possible. During point placement, GCPs can jump or change location when subsequent points are added. Also the control point error for existing points can be adjusted upward automatically as new points are added, an indication of how the points work together to make the transformation.
- Save input and reference points for each image. They can be called up as needed for making changes, adding or deleting points, and checking for common points in overlap areas of those images to be mosaicked. The addition of well-placed GCPs may help increase registration accuracy.

6) Resample each image.

- Select the resampling method. The nearest neighbor sampling technique was applied at the Hidden Ranch study area.

7) Check the georeferencing of each frame.

- As images are georeferenced, display adjacent images that have already been georeferenced and check how the overlapping areas line up. Expect some displacement at the edges of the images. In an area like Hidden Ranch with a lot of relief displacement, expect more displacement at the edges of the imagery than at study sites with gentler topography such as the Etiwanda site. If the images do not line up well, determine which image(s) have the most error and repeat step 5.

8) Mosaic frames together to create an image map.

- Trim overlapping areas from each frame. For the Hidden Ranch site, this was accomplished by creating AOI files for each frame to trim the excess overlap.
- Add the frames to the mosaicking viewer, select a joining method, and combine. The feathering option was used for Hidden Ranch site.

Results

Figure 8 is a false color composite of the resulting ADAR mosaic for Hidden Ranch. The registration and mosaicking results were quite good, but offsets were apparent in some areas. Displacement was especially noticeable where offsets co-occurred with linear features. Misregistration errors were noticeable in overlap and sidelap areas between adjacent frames, resulting in image feature doubling. For frames where misregistration occurred, registration could be improved by additional cropping of overlap areas prior to mosaicking. Using additional common reference points and excluding other GCPs in overlap areas would probably make an additional improvement. Using a digital elevation model as a reference might have improved registration if one had been available.

6.4.4 Registration to Existing ADAR Image Maps and Mosaicking - Sycamore Hills Case Study

Sycamore Hills ADAR Image Data

ADAR 5500 imagery was collected at a 1.0 m spatial resolution during the summer months of 1996, 1997, and 1998. For each year, 2 to 3 image frames corresponded to the extent of the Sycamore Hills study site. These images were from one flight line having 60% endlap. Variations in sensor and sun position influence change detection results (described in Section 8.0). Therefore, the date, time, and solar information specific to each acquisition are shown below.

	date	***time (PDT)***	***solar zenith***	***solar azimuth (Deg. from North)***
1996	July 29	11:45	15.3	169
1997	July 30	3:15	46.5	263
1998	June 24	12:15	11.3	206

Image to Image Map Registration and Mosaicking

To detect and identify land cover changes from multitemporal ADAR imagery, newly acquired ADAR frames are registered to extant ADAR image maps derived from data captured in previous years. Procedures for registering ADAR imagery to an existing ADAR image map are very similar to those of registering ADAR imagery to a digital orthophotograph. Two factors that may make these two procedures slightly different are (1) image features common to both ADAR 5500 images may be easier to identify due to more similar spectral-radiometric values between the ADAR images; and (2) extant ADAR image maps may have different extents of coverage whereas digital orthophotograph data are usually quite extensive and would not be limiting in coverage.

Prior to change detection analysis ADAR 5500 imagery acquired in July 1996 and June 1998 for Sycamore Hills were registered to a 1997 ADAR image map. The 1997 map was generated by georeferencing individual frames based on ground control points that had been surveyed with a GPS and marked with high reflectance targets, and then mosaicked into a single image map. Through the process of frame to image map registration, the output registered 1996 and 1998 imagery were both georeferenced and rectified (corrected for inherent image distortions and given map-like qualities). The procedures for registering ADAR 5500 image data to an existing image map and mosaicking them are:

1) ***Open the non-registered imagery and the image map in viewers and position adjacent to each other.***

2) ***Place well-distributed GCPs upon features common to both the image map and the non-registered images.***
   - Twenty five to twenty nine GCPs were placed on features common to both the image map and each of the non-registered images for the Sycamore Hills site. Care was taken to select features representing a variety of elevations across the scene; ridge top and valley features were used.
   - Control point RMS error information should be used to evaluate the quality of individual ground control points. If the error for a small number of GCPs is high, these points should be reviewed for placement precision. If the error from these individual points cannot be reduced, consider deleting these points.
   - Obtaining an overall RMS error of 0.5 pixels for all ground control points is the goal during the GCP locating process. Local topography and/or inherent inaccuracies within the base image mosaic are likely to increase the overall RMS error for the transformation model. Overall RMS errors for the 1996 and 1998 images from the Sycamore Hills site ranged from 1.8 to 3.3 pixels (meters).

3) ***After placing all GCPs and deriving a satisfactory RMS error, apply the transformation and resample the individual image scenes.***
   - Choose a transformation order and resampling method.
   - A second order transformation using bi-linear interpolation was applied to resample the Sycamore Hills 1996 and 1998 imagery.
   - A post-registration evaluation of the registration precision between the 1996 and 1998 imagery and the 1997 image mosaic was performed using most of the GCPs utilized in the registration process. The following registration RMS errors were calculated: 1996 to 1997, 4.17 m; 1997 to 1998, 2.88 m; and 1996 to 1998, 2.57 m.

Following registration to the 1997 image map, the individual registered frames from 1996 and 1998 were mosaicked to create image maps for each year. The georeferencing information associated with the image scenes following the frame to image map registration process provided the necessary information about the relative positions of the scenes.

The following steps describe how to create an image map by mosaicking individual georeferenced image frames.

(1) ***Trim overlapping areas from each frame.*** The endlap between image frames contributing to the 1996 and 1998 mosaics was reduced in an attempt to remove portions of the image frames having the largest view zenith angles. This was performed due to concerns that scene reflectance might vary with view angle at the

larger view zeniths. This concern was largely unrealized, as inflated digital number values thought to be associated with increased view zenith were found to be more closely associated with topographical variations and bare soil conditions. Limiting the extent of individual image frames incorporated into the mosaic was accomplished by digitizing a polygon outlining the limited extent, saving that polygon to a file, and using that file within the mosaic tool to specify the limited extent.

(2) ***Add ADAR frames to mosaicking viewer.*** Two images from 1996 and three images from 1998 contributed to create the mosaics for Sycamore Hills.

(3) ***Select joining or overlap method and execute mosaicking process.*** The feathering option was used with the 1996 and 1998 Sycamore Hills mosaics. This option may be preferable with many applications because the averaging procedure uses information from all image data inputs and the use of weighted averaging reduces hard edges and results in seamless, visually appealing image mosaics.

6.4.5 OrthoMax and Other Software Packages

To generate highly accurate image maps with positional errors less than 2-3 meters requires that images be corrected for the effects of varying topographical relief, platform altitude variations, and sensor distortions (Jensen, 1995). Southern California Edison has the option to generate precision ADAR ortho-image mosaics "in-house" with the aid of softcopy photogrammetry software such as the ERDAS Imagine OrthoMax module which runs on Unix workstation computers. The accuracy of the resultant digital ortho image is a function of the precision of the ground control, knowledge of ADAR camera geometric characteristics, the success of the photogrammetric triangulation process, and the accuracy of the DEM used to correct for relief displacement. Most importantly, the ADAR image frames must be captured with sufficient, stereoscopic overlap (60%), to enable proper photogrammetric correction.

The OrthoMax orthorectification process utilizes a block triangulation approach. This involves numerical transformations from the original to the corrected image data based on the geometry of the sensor and the relative orientation of adjacent, overlapping frames. The user need only use the 'Orthorectify' command in the 'Ortho Tool' of OrthoMax and the 'Block Tool.' In order to use the Block Tool, camera parameters such as interior orientation elements (focal length, fiducial points, and radial distortion values) are first input into the software package. After the interior orientation elements are input, exterior orientation elements (normally ground point measurements of horizontal and vertical positions surveyed with GPS) are then manually entered using the 'Ground Point Measurement' command of the Block Tool (i.e., matching points on the to-be-triangulated images with ground control values). After all elements are entered, the block triangulation routine is run. The subsequent triangulated image is then used in the 'Ortho Tool' to create the orthorectified image.

In order to create orthorectified imagery using OrthoMax, precise information is required on camera interior orientation elements such as fiducial locations, radial distortion values, principal point location (determined from fiducial locations), and focal length. These model parameters are generally determined via laboratory calibration. The ADAR 5500 system, however, has not been geometrically calibrated and the fiducial locations and radial distortion values are unknown. Also, the ERDAS OrthoMax softcopy photogrammetry software does not support laboratory calibration procedures for determining the interior orientation parameters of a camera.

The fiducial locations can be defined as four points on each corner of the red band image, which is the waveband image that is the base for the band-to-band registration process that has been applied by Positive Systems Inc. prior to receipt of data. Each pixel has a diameter of 9 micrometers and the charged coupled device (CCD) has 1536 x 1024 pixels. Therefore, the fiducial locations, in units of micrometers, are ±6912, ±4608 with the principle point at the center of the image at 0,0.

The nominal focal length for the Kodak DCS 420 digital cameras of the ADAR System 5500 is listed at 20 mm, but the actual focal length may vary for each image acquisition and should be estimated. Through our sensitivity analyses that were based on empirical validation with GPS survey points, the actual ADAR focal length appears to be less than 20 mm and may even approach 19 mm.

Radial lens distortion information is typically required to generate highly accurate ortho-images and is usually available from the camera calibration certificate. However, the Kodak DCS 420 cameras that comprise the ADAR 5500 system do not have calibration certificates. When they are available or can be derived from laboratory calibration to geometric targets, the 'Camera Editor' in OrthoMax is used to enter radial lens distortion values lens distortion values (in microns) for 10 degree increments of field-of-view angle. Our empirically based sensitivity analyses comparing no specification of radial lens distortion with default values in OrthoMax resulted in minor (< 0.1 m) improvements in horizontal accuracy.

A DEM is required as input for correction of relief displacement, which may be supplied from existing sources (e.g., USGS or commercial providers), or may be generated from scanned stereo aerial photography, or potentially, from the same stereo ADAR imagery used to generate image maps. Standard USGS DEMs based on 1:24,000 topographic quads seem to provide reasonable input elevation data. Our sensitivity analyses showed little difference when input DEMs had raster sizes of 10 and 30 meters. (Note that these DEMs were created by interpolation of scanned contours that had undergone rigorous editing and may not represent the typical USGS DEM product.)

Implementation of softcopy photogrammetry by SCE for purposes of generating image maps of habitat reserves is likely not warranted at this time, unless the company requires image maps for a broader number of applications, or wishes to become a general provider of geometric image processing services. Future generation ADAR systems and those of competitors are likely to be subjected to more rigorous calibration of interior orientation parameters which will be made available to users. Also of note, several other commercial softcopy photogrammetry software packages are available that are easy to use and provide reasonable orthorectification and DEM generation capability, and ERDAS will soon be releasing another, similar module designed for PC-NT users.

7.0 VEGETATION CLASSIFICATION AND MAPPING

Remotely sensed imagery can be classified into vegetation and land cover categories using a variety of methods, including: automated clustering algorithms which group spectrally similar pixels; hands-on, visual interpretation; or a combination of the two. Research conducted at the Sycamore Hills study site in 1997 and 1998 (Brewster et al., 1998, p. 20) found that a hybrid method that combines both automated cluster based methods with visual "on-screen" interpretation produced the best results when working in a coastal sage scrub habitat environment. This procedure was again found to produce the best results in 1998 - 1999 at the Hidden Ranch and Etiwanda study sites. Figure 9 illustrates the sequence of major steps in the hybrid classification process.

If one compares the Hidden Ranch and Etiwanda sites, it becomes apparent that the two sites are quite different from each other in topography, geographic setting, and vegetation type and cover. At the Hidden Ranch site, we see vegetation types similar to those at the more coastal Sycamore Hills site with the addition of other chaparral types. While at the Etiwanda site, we see new sage scrub, chaparral and woodland habitats. The basic approach used to classify the vegetation at these two sites was the same, but the results and the manner in which the imagery was interpreted varied due to differences between the two sites.

After image maps were produced for both sites, as described in section 6.0, semi-automated classification techniques were used to group pixels into spectrally similar categories, based on the premise that different vegetation and land-use categories reflect and absorb electromagnetic energy in distinct manners and, therefore, produce unique signatures. The resultant images were labeled based on knowledge of the sites and ground reference data produced through conventional field mapping. These images, as well as large format printouts of the unclassified ADAR imagery were taken to the study areas and classes were labeled during a reconnaissance visit. Based on the knowledge and experience gained from the first field visit to each site, the automated classification techniques were specifically tailored for each site to maximize the amount of useful information derived from each automated classification. A second site visit was then scheduled to check class labels, resolve confused classes, and manually draw class boundaries if they were not apparent on the imagery. After the second site visit, a combination of the automated classification results, field maps, and visual interpretation of unclassified image maps was used to manually digitize vegetation class boundaries on-screen. The resultant vector files were used to create a GIS database for each site. Below is a detailed list of procedures used to classify the Etiwanda and Hidden Ranch data sets.

1) ***With the image processing software program of choice, run an automated, unsupervised classification procedure on the image mosaic.***
   - ***Specify an input raster file (the mosaic to be classified) and an output file.*** Depending on the software used, a signature file may need to be specified as well.
   - ***If more than one choice is available, choose a clustering method.*** ERDAS Imagine, for example, only offers one choice, ISODATA (Iterative Self-Organizing

Data Analysis Technique), which is a standard method offered by most image analysis software packages. The method uses the minimum spectral distance to form clusters, and begins with random cluster means or the means of an existing signature set.

- ***Select the number of classes.*** At both the Hidden Ranch and Etiwanda sites, 20 classes were selected. For the first clustering, use a fairly low, round number. This first pass at classification is designed to familiarize the user with the data and get a general idea about how the data are clustering.
- There are other options that can be selected such as: skip factor, number of iterations, and the convergence threshold. For the most part, the user can safely apply the defaults. For both study areas, the default skip factor of 1 in both the x and y axis was used, the default convergence factor of 0.95 was used, and the number of iterations was increased from the default of 6 to 9. Increasing the skip factor will increase processing speed, but will skip pixels in the generation of spectral clusters. The convergence threshold is the maximum percentage of pixels whose cluster assignments can go unchanged between iterations. The iterations option is the maximum number of times the algorithm should recluster the data. Increasing this number increases the processing time, but might increase the accuracy.
- ***Specify areas to be masked out of the classification.*** If there are portions of the image map that don't need to be classified, the user can specify a vector coverage that excludes these areas. In ERDAS, this is called an area of interest (AOI). In the Hidden Ranch example, an AOI was used to mask parts of the imagery out of the study area boundary. At Etiwanda, an AOI was used to mask out urban areas as well as areas outside the study area boundary. Masks can be very useful if large areas that will ultimately be classified into one category (e.g., developed) exist within the imagery, but lack one distinct spectral signature that easily distinguishes them from surrounding areas. Using masks can save both time and frustration.

2) Label the image derived from step 1.

- ***Open the image created in step 1.*** It will appear in gray scale.
- Before a cluster classification is labeled, the user must have a clear idea of the classes and level of classification desired (i.e., level of detail). This is among the set of parameters determined during the project planning stage.
- ***Use the raster attribute editor to change the colors of the classes and label them.*** If the user lacks knowledge about the site and has no ancillary data, labeling can be difficult. If the image cannot be labeled immediately, then use a color slice to assign color to the classes. This will quickly reveal how the data are clustered.

3) First field visit to label classifications.

- ***Before the field visit, print out large color plots of both the unclassified ADAR and the classifications from step 2.***

- ***Drive and walk the site, labeling clusters and making notes regarding vegetation class boundaries.***
- ***If there is an existing vegetation map, check it for accuracy.*** At the Hidden Ranch study area, we found a number of errors in the GIS database. Three examples of errors are: a patch of wild roses labeled as sagebrush-buckwheat; mulefat labeled as southern willow scrub; and various patches of vegetation that were labeled buckwheat, which did not exist at the time of our field visit. Our interpretation of correct class labels and species composition also varied. Examples are: areas that were mapped as southern mixed chaparral which we interpreted as mixed sage with patches of southern mixed chaparral; areas mapped as sagebrush, we interpreted as having a more varied species composition and labeled as mixed sage; and a few areas that were mapped as chamise chaparral we interpreted as a more mixed class of maritime chaparral-sagebrush.
- ***If a quantitative accuracy assessment is desired, use a GPS to record the locations of vegetation classes selected by biologists.*** The selected points should be representa-tive of the classes of vegetation at the site, be well distributed throughout the site and have at least three samples for each vegetation class.

4) Repeat step 1, refining the technique based on knowledge gained during the field visit.

- Repeat the unsupervised classifications performed in step 1, increasing the number of classes based on what was learned in the field. At the Hidden Ranch site, the number of classes was increased to 30. Structurally, the Hidden Ranch site is relatively simple and the ADAR imagery did a good job of differentiating classes. At Etiwanda, the number of classes was increased to 30 and then 40. The Etiwanda site has more complex vegetation patterns and the classified image differentiated vegetation into a large number of classes which did not correspond well with distinct taxonomic categories. The categories that we were trying to classify (e.g., Riversidian sage scrub and the three seres of alluvial fan sage scrub) consist of a complex mosaic of different plant species that have much different reflectance values. Although it was not performed in this study, aggregating the pixels eliminates some of the detail and can result in more satisfactory results.
- If there is some trouble defining classes, this is the time to experiment with the data. As stated previously, pixels can be aggregated if there is too much detail. Another option is to break the study area into smaller, more manageable sections and classify each separately. This can be useful if the study area is large like the Etiwanda site.

5) Second field visit.

- Before the field visit, print out large color plots of the classifications derived from step 4 and bring the plots created for the first field visit as well.
- The purpose of this field visit is to draw vegetation class boundaries if necessary and address unresolved classification questions.

6) ***On-screen interpretation and digitizing to produce a final vegetation map.***

- At the three sites discussed in this report (Sycamore Hills, Etiwanda, and Hidden Ranch) it was found that the strict use of automated classification methods did not yield satisfactory results. Therefore, a hybrid approach was undertaken which blends both automated cluster based methods and field checks with "on-screen digitizing" using both the image classification and image mosaic in the computer laboratory.
- First, create a blank GIS layer or ArcView Shape file.
- In the image processing or GIS software package of choice, display both the image mosaic as a false color composite and the color-coded classification created in step 4.
- Use a line tool to create vegetation class boundaries. Utilize the plots that were taken to the field and labeled in conjunction with the on-screen images to help determine class boundaries. Using the unclassified and classified ADAR image maps in combination aids in detecting class boundaries. In some cases, one image will be more helpful than the other. For example, at the Etiwanda site, the mature alluvial fan scrub was easily detected on the unclassified mosaic, because mahogany, which distinguishes intermediate from mature alluvial fan scrub, "popped out" of the imagery in an almost 3-D manner. On the classified image, the mahogany was not nearly as apparent. The unclassified image can be very useful for detecting differences in texture and tone, which give clues regarding the type of vegetation present and the boundaries. At the Hidden Ranch site, the unclassified imagery defined the edges of the grasslands quite well, while the classified image provided excessive detail because it was picking up density differences and some of the background soil characteristics which were not of interest for this study. The classified imagery at the Hidden Ranch site did an excellent job of detecting the boundaries of woody chaparral patches, while they were not as obvious on the unclassified mosaic.

7) Turn vector product created in step 6 into a GIS layer.

- When the on-screen digitizing is complete, use a GIS package to create polygon topology, correct errors in the coverage (unclosed polygons, dangling arcs, etc.,), create polygon attributes, and label the polygons. Arc/Info software was used for our case studies.

8) Qualitative and/or quantitative accuracy assessment.

- The new vegetation map can be qualitatively assessed for accuracy by a return visit to the study area to check that polygons are labeled correctly and their boundaries drawn accurately.
- A quantitative accuracy assessment can be achieved by comparing vegetation sample points collected with a GPS to corresponding polygon vegetation labels. Most image processing software packages include accuracy assessment capabilities, although the calculations can be easily set-up and performed in any spreadsheet software package (e.g., Excel). A quantitative accuracy assessment was used at the Sycamore Hills study site for the 1997-1998 project year. For a detailed discussion of the methods used at that site, see "An ADAR Based Habitat Monitoring System" (Brewster et al., 1998, p. 23 - 26).

Results

ADAR classification maps for the Etiwanda and Hidden Ranch study sites are shown in Figures 10 and 11. The effectiveness of classification procedures differed for the two sites. This is to be expected, because of the differences in vegetation type and environment. The 1998-1999 study year was the first look at the alluvial fan scrub environment represented by the Etiwanda study area using ADAR image data. Many of the vegetation classes that we were trying to map at the site are very complex and species rich, which when classified using ADAR gave an overwhelming amount of detail. Because of this, the visual interpretation of the imagery along with the field notes became a very important part of producing the final vegetation map. The classification did an excellent job of delineating channels, road features, and the burned area. The vegetation class boundaries that we were trying to map at the Hidden Ranch study area were much easier to define. This is due to several factors, most importantly, the vegetation at the Hidden Ranch site is less complex, both in its species composition and number of community types. Secondly, the site is smaller, and therefore more manageable. Finally, it more closely resembles the vegetation types we encountered previously at Sycamore Hills and therefore is more familiar to us. Overall, the hybrid approach applied to both sites worked quite well. The vegetation maps derived from ADAR and conventional methods do show discrepancies. These differences are accounted for by the different acquisition dates of source images, differing interpretations of class ownership and boundaries, varying levels of detail, displacement errors, and limited ground-based assessment for both the ADAR and conventional methods.

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8.0 CHANGE DETECTION AND ANALYSIS

Image change analyses were performed using multi-year ADAR 5500 imagery acquired for the Sycamore Hills study site during the summer months of 1996, 1997, and 1998. An emphasis was placed on detecting and identifying land cover changes occurring during the Summer 1996 to

Summer 1998 period. Change detection using multitemporal image data involves comparing image brightness values or derived products such as vegetation indices and classification products between two or more time periods. The underlying assumption is that changes in land cover results in changes in brightness values and/or derived products from the image data and therefore, can be detected using remote sensing instruments. The utility and methodological requirements of several methods of change detection techniques were assessed in the context of monitoring changes in habitat condition and land cover characteristics within shrubland habitat reserves.

8.1 Radiometric Normalization

A useful first step that is performed prior to comparison of brightness values is radiometric normalization. Radiometric normalization procedures are applied in an attempt to standardize image brightness values and minimize differences that can result due to varying atmospheric conditions, solar illumination conditions (i.e., solar position), sensor settings (aperture, shutter speed, detector sensitivity/gain), etc. Such normalization is performed for one or more image dates relative to a base image, such that like waveband images are referenced or radiometrically registered to an image captured for the same wavebands as the reference or base image. Normalization procedures should be applied to individual image frames prior to mosaicking. Normalizing the image data allows for more direct comparison of brightness values between dates. However, radiometric normalization should be considered as an optional processing step that achieves relative, but not necessarily absolute normalization between image dates. Useful enhancements of land cover changes can be achieved without having first normalized multitemporal images, particularly when post-classification comparison approaches (described below) are utilized as a change detection procedure.

The multitemporal ADAR 5500 image data were radiometrically normalized to the 1997 year base following completion of the image to image geometric registration discussed in section 6.4.4. Two radiometric normalization approaches, pseudo-invariant features and histogram matching, were evaluated.

The first method tested was the pseudo-invariant features approach where brightness values from one image are aligned with another using a linear offset function. The function is determined by selecting brightness values associated with multiple invariant features from the two dates of imagery. Such features are radiometric calibration points that are considered to have nearly constant spectral reflectance for the multitemporal image pair being normalized to one another. Normally the scene characteristics associated with these calibration points are unvegetated, man-made features, rock outcrops, or exposed soil and sediment. Because the features are "invariant," differences in mean and variance (expressed in the linear offset function) between the samples from the two dates are used to calibrate a linear transformation for adjusting all image values from one date so as to match values from a reference year.

Procedures

1) Identify multiple pseudo-invariant features that are common to both the reference imagery and the imagery to be normalized. These features can vary in size from a few pixels to a few hundred pixels and again, usually are unvegetated. Pseudo-invariant features containing multiple pixels (50 to 200) are recommended so as to reduce the high frequency variation that may be found in a small sample of image data.

2) Use areas of interest (AOI) tools to delineate sample polygons from within the full extent of the pseudo-invariant features and to extract the statistical information (signatures) from those AOIs. Perform this step to extract samples for both the reference and the non-normalized imagery. It is recommended that 15 to 30 pseudo-invariant features be identified per frame in order to develop the relationship between the radiometric values of the reference and non-normalized image data.

3) Extract the mean values from the pseudo-invariant feature samples for both data sets (reference and non-normalized) and export these values into software that can perform simple linear regression. The Microsoft Excel spreadsheet software package can perform this function and was used for the example in this report.

4) Perform a simple linear regression using the sample mean values from both data sets and obtain the least squares, linear relationship between the two data sets. Verify that mean values from like samples (identical pseudo-invariant features) are being used to develop this relationship.

5) Obtain the equation for the least squares line that describes the relationship between the two data sets. This can be accomplished in Excel by plotting the values from the two data sets against each other using the scatterplot function, right clicking the mouse on one of the data points, and selecting add trend line (linear), and display equation on chart. Be sure that the reference data values are plotted on the Y-axis and the non-normalized data values are plotted on the X-axis.

6) Use the equation provided by the least squares relationship to convert the non-normalized data values to normalized values that match the reference data values. This is accomplished by multiplying the non-normalized values times the slope of the least squares line and adding the y-intercept value.

7) Repeat the above steps for each waveband image.

The second method of radiometric normalization tested was a type of histogram matching approach. In this approach, rather than matching brightness values from several pseudo-invariant features, the digital values for all pixels representing the study area were extracted and the mean and standard deviation values of the distributions for each image date were matched to those values of the reference year. The assumption in this approach is that "on average," the land cover did not change between the two dates. Therefore, the mean and standard deviation of the image brightness values should be nearly the same for both dates and any changes will result in a deviation from normalized values between dates. The histogram matching radiometric normalization approach was utilized in the Sycamore Hills study prior to all change detection analysis.

Procedures

1) Use image masking procedures to set all image values not associated with the study area to a value of zero; and recalculate the image statistics ignoring zero values. This step is optional and may be performed to reduce the total variation of the scene that is to be normalized.

2) Extract the mean and standard deviation values of the image pixels with non-zero values (masked) in step 1, for both the reference and the non-normalized image data.

3) Using the mean and standard deviation values from both data sets calculated in step 1, convert the non-normalized image data to normalized image values that match the reference data.

   To perform this task, apply the following equation to the non-normalized image data:

   $$(NN\text{-}mean_{NN}/stdev_{NN}*stdev_{R})+mean_{R}$$

where:

NN = the non-normalized data
$mean_{NN}$ = mean of the non-normalized data
$stdev_{NN}$ = standard deviation of the non-normalized data
$stdev_{R}$ = standard deviation of the reference data
$mean_{R}$ = mean of the reference data.

4) Repeat the above steps for each waveband image.

8.2 Change Detection Methods

Several methods of change detection were reviewed and/or evaluated using the ADAR 5500 image data from Sycamore Hills. These methods include:

- differencing of the individual ADAR 5500 spectral bands;
- differencing of the Normalized Difference Vegetation Index (NDVI);
- differencing of local spatial variation measures of waveband images (image texture);
- differencing of local spatial variation measures of NDVI images (NDVI texture);
- change vector classification; and

- multitemporal image classification comparisons.

Each of these methods may provide different information on land cover change and each method requires that different image processing procedures with varying complexities be applied. A schematic representation of the varying types of processing applied to the multitemporal ADAR 5500 imagery is presented in Figure 13. Once again, the image basis for all change detection approaches tested was the multitemporal ADAR 5500 imagery for 1996,1997 and 1998. Subsequent processing included:

- differencing of the brightness values;
- differencing of derived products having continuous values; and
- comparison of derived products containing categorical information.

Figure 13 represents a reference for the following discussion.

8.2.1 Spectral Image Differencing

Image differencing is the simplest approach to change detection. Image differencing was performed by subtracting spectral waveband images from the earlier date of imagery from the corresponding waveband image from the later date of the multitemporal data set. The output of this process was a single band difference image in which low values (dark) represent change from brighter (i.e., higher reflectance) in the first date to darker in the second, medium (gray) levels represent areas of no brightness change, and high values (bright) represent change from darker to brighter over the time interval. The gray-scale values that are output from image differencing may be grouped into interval classes of relative magnitude of change. This type of change magnitude classification is usually performed using measures of variance from the difference image mean as threshold levels for defining breaks between 'change' and 'no-change' classes.

Procedures

1) Subtract the earlier date image from the later date image. ADAR 5500 data are provided in integer, or also called, unsigned 8-bit format (values range from 0 to 255). Difference image values should be output as signed 16-bit so that difference values can range from a possible –255 to +255. While this is the maximum possible range, data values will most likely range between –100 and + 100 and can be specified as signed 8-bit (maximum range –127 to + 127). Additionally, values can be increased by 100 (add 100 to all) and specified as unsigned 8-bit; in this scenario, a value of 100 represents no change. Some image processing software packages only handle unsigned 8-bit data values.
2) Group difference images into interval classes by using mean and standard deviation statistics. Interval classes provide more general information on the magnitude and direction of differences. For example, difference image values that are two standard deviations above the

mean and greater represent a change from lower values in time one to higher values in time two (such as land cleared for development).

3) Determine the classes of interest. Individual classes will correspond to a particular range in difference values.

4) Identify the mean and standard deviation values of the difference image.

5) Use conditional statements in image processing models to set continuous input values from ranges identified above to thematic output, where pixel values represent the difference class.

Difference images were created for each spectral band and each combination of years from the Sycamore Hills case study. These images were grouped into seven interval classes using difference image mean and standard deviation values. Class ranges were determined by measures of standard deviations from the mean and were specified as:

Range (stdev)	Class
< -2.5	1
-2.5 to -2.0	2
-2.0 to -1.5	3
-1.5 to 1.5	4
1.6 to 2.0	5
2.0to 2.5	6
> 2.5	7

6) Apply 5 x 5 focal majority windows twice (repetitive runs) over the interval class image to remove (re-classify) isolated pixels and spatially generalize the resultant change interval class image. This step was performed for all Sycamore Hills change classification products.

Difference images were created for individual wavebands. These single band difference images were "stacked" into a multiple band difference image and the combined information was exploited.

8.2.2 Change Vector Classification

An approach to image change detection and/or identification called change vector classification utilizes multiple band difference images as input to automated image classification. The output thematic classes represent general types of transitional changes or no-change. Unsupervised image classification using routines such as the ISODATA routine discussed previously was used with the change vector approach to classify the multiple band difference images into change and no-change classes. In addition to image differencing, the change vector approach was the other primary image processing approach tested for the Sycamore Hills study site.

Procedures

1) Stack multiple difference images into a single image. These difference images may include individual waveband, vegetation index (e.g., NDVI, described below), texture difference image, or other continuous value (i.e., not categorical variable) images, as discussed below in greater detail. For the Sycamore Hills study site, the red spectral band difference image and the NDVI difference image were the inputs for the change vector classification.

2) Classify the multiple band difference image. Input this image into the unsupervised image classification routine (e.g., ISODATA) and specify the number of desired cluster classes to be output. Thirty cluster classes were output for the Sycamore Hills site. A single band, thematic image with the specified number of classes will be created. In addition, a file with signatures for each of the output classes may be created by the unsupervised classification program. This signature file is useful for determining the types of changes identified by the individual classes by plotting class means onto band to band scatterplots (called feature-space).

3) Assign class labels to the cluster classes of the thematic image using information about the type of change (e.g., increase in a vegetation index over time would indicate increased vegetation cover), and/or knowledge derived from field experience gained before or after performing change vector classification, and/or from on-screen analysis of the multitemporal ADAR data set.

4) Apply 5 x 5 focal majority windows twice (repetitive runs) over the interval class image to remove (re-classify) isolated pixels and spatially generalize the resultant change interval class image.

8.2.3 NDVI Differencing

The Normalized Difference Vegetation Index (NDVI) provides information on vegetation leaf area, biomass of photosynthetic materials, and condition. The NDVI was calculated for every pixel as (NIR-Red)/(NIR+Red), where NIR represents digital number, or spectral radiance, or spectral reflectance values for the near-infrared waveband and Red is the like quantity for the red waveband. The image differencing approach was applied to the individual NDVI images to highlight changes in vegetation condition. Difference images were generated with multitemporal NDVI images. Similar to difference images from individual spectral bands, NDVI difference images are single band, continuous gray-scale images where high or low departures from the mean tend to represent a higher magnitude of change in vegetation abundance. As with waveband difference images, NDVI difference images were grouped into interval classes of change.

8.2.4 Texture Differencing

Image texture refers to a measure of local brightness variation around an individual image pixel. A measure of variation can be derived by passing a moving window operator over each pixel in the image (usually a 3x3 or 5x5 window), calculating the variance of the pixels falling within that window, and outputting the variance measure into the pixel that corresponds to the center of the moving window. This moving window is passed over all pixels within the image, the variance around each pixel is calculated, and an image containing only measures of local variance for each pixel is output. This output image is referred to as a texture image because the output pixel values indicate the magnitude of brightness texture (or local heterogeneity) around that image pixel. Because the calculated variance is a local measure (only provides information on pixels near the pixel of interest), texture images are most useful for identifying abrupt changes in brightness such as a trail cutting through a patch of chaparral. Therefore, texture difference images may be useful for identifying changes in features that have abruptly brightness variations over short distances (e.g., erosional features and trails).

NDVI texture differences were also created in the same manner as the texture images described above, with the exception that texture was calculated using NDVI values rather than the original multispectral brightness values. NDVI texture images are most useful for identifying local changes in vegetation cover.

8.2.5 Post-classification Comparison

A method of change detection that does not utilize image differencing is post-classification comparison of derived image classifications. The output of this approach is a time sequence of thematic categorical data, which is often useful in identifying substantial changes in land cover types. The first step involved with this change detection approach is to classify both dates of ADAR 5500 imagery independently, using a supervised or unsupervised image classification approach. Once acceptable classifications have been produced for both time periods, changes in class memberships apparent from each classification map can be derived and summarized. Two approaches for evaluating the apparent class membership change between two dates are: 1) produce an image that illustrates from-to changes and non-change over space; and 2) produce summary statistics and tables that provide information on the extent and type of from-to change and non-change. Commercial remote sensing and GIS software often provide functions that can be used to create these types of evaluation products (e.g., MATRIX and SUMMARY routines in ERDAS Imagine).

The 1996 and 1998 ADAR imagery from the Sycamore Hills site were classified into nine community level classes. Changes between the classification products from the two years were visualized by creating an image that illustrated the from-to class changes. Note that the post-classification comparison is most likely to be effective when applied to multitemporal image pairs that are at least five years apart, or in areas of more dynamic land cover changes (e.g., associated with urbanization, or recent or frequent fires) than occurred at Sycamore Hills.

8.2.6 Change Detection Results

All change detection techniques described previously were applied to the ADAR data sets to detect and identify changes in land cover and habitat condition at the Sycamore Hills site between 1996 and 1998. While change detection was performed for all two-year combinations with the 1996, 1997, and 1998 ADAR 5500 image data, results presented here reflect only changes detected using 1996 and 1998 maps and selected change detection techniques. A team of seven researchers attempted to verify apparent changes indicated from image-based procedures by field reconnaissance on May 5, 1999.

The 1996 to 1998 difference results are presented in Figures 14 to 17. The following change detection products are illustrated in these figures, respectively:

- difference magnitude interval classes derived as a composite of the differences of ADAR visible bands (blue, green, and red);
- NIR difference interval classes;
- NDVI difference interval classes;
- change vector classification.

Interval classes of the difference images (Figures 14 to 17) are color coded to show an increase in value from 1996 to 1998 as pink to red and a decrease in value from 1996 to 1998 as light to dark blue. Each direction of change (increase or decrease) contains three classes representing different magnitudes of change; high intensity colors (lighter) represent low magnitude changes in value over time, while low intensity colors (darker) represent high magnitude changes in value. The interval thresholds were determined using the standard deviation ranges described previously (Section 8.2.1).

The thirty output classes from the change vector classification have been aggregated to represent either increase in vegetation cover/decrease in soil exposure, decrease in vegetation cover/increase in soil exposure, or no change. Many of these change detection products identify similar apparent changes and many reveal unique features of apparent change.

Selected areas of interest that show up as apparent change in many or all of the change detection products are indicated in Figure 18 and are the focus of the following discussion. These features are numbered to facilitate identification. All changes identified using change detection techniques with the 1996 and 1998 imagery represent one of three types of apparent changes: (1) actual land cover change; (2) change associated with differences in season and/or climate; and (3) artifacts of the change detection process. These three types of apparent change are indicated in Figure 18 by (1) yellow, (2) green, and (3) blue lines, respectively.

Actual land cover changes that have been validated through field reconnaissance are evident in many of the change image products. Feature 2 is evident in the NIR, NDVI, classification, and change vector change products. This feature is a large patch of poison oak that invaded surrounding coastal sage scrub (CSS) habitat between 1996 and 1998. Feature 4 is a small water body that formed and was eventually encompassed by herbaceous cover. Feature 4 is evident in all change detection products except the visible band composite difference. Features 6 and 7 represent two trail features that were widened over time and are evident in visible composite, NIR and change vector products. The change phenomenon indicated by feature 8 pertains to sand sedimentation following the substantial precipitation, runoff and erosion of the Winter 1998 El Niño phenomenon. This feature is evident in the visible composite, NIR, and change vector products. When this area was visited in May 1999, it was largely covered with new grasses. Features 15 and 17 are a parking area and dirt road that have re-vegetated following a halt to the usage of each. This change was detected by the visible composite and the change vector products.

Many apparent change features indicated in Figure 18 are associated with vegetation phenology differences between the late-July, 1996 and late-June, 1998 acquisitions, that are associated with variations in season and/or climate. This type of cover variation can occur when imagery is collected on different annual dates, or if precipitation and other climatic factors are substantially different between years. Features 1, 12, and 13 are changes in herbaceous type cover that may be associated with community composition change, but are most likely due to seasonality/climate changes. During the 1999 field visit, Feature 1 was identified as ragweed (*Ambrosia sp.*). Features 5, 9, 10 and 14 are located in areas largely consisting of coastal sage scrub and chaparral vegetation. The change detected in these areas between 1996 and 1998 is most likely associated with a difference in phenology resulting from seasonality and/or climate variations. The 1998 imagery was collected one month earlier than the 1996 imagery (late June versus late July) and the 1998 season was very wet due to the occurrence of El Niño conditions. Change features 10 and 16 correspond to sycamore trees found within a valley area. The detected changes are associated with a less dense leaf canopy during the seasonally earlier 1998 acquisition. The change features resulting from differences in phenology discussed above are largely apparent in the NIR, NDVI, and change vector products.

Some apparent changes can be characterized as artifacts of the image processing approach to change detection. These apparent change features may be caused by such things as geometric or radiometric misregistration between the multitemporal image data, or they can be caused by variable reflectance from a scene due to differences in solar illumination and/or view angle between dates. Feature 3 represents an area that appears as change in most of the change detection products. This change feature results from variable illumination conditions between 1996 and 1998 and is enhanced in this portion of the study area due to steep and variable topographical relief. Although the images were both acquired within thirty minutes of the same time of day, the solar zenith angle varied sufficiently for the June and late July acquisitions and apparently resulted in differences in shadowing and shading. Features 11 and 18 show apparent change that can be attributed to geometric misregistration between the 1996 and 1998 image maps.
Summary matrices indicating the areal extent and direction of apparent change per community level vegetation class were created using the visible bandwidths composite and NIR bandwidth difference images that were classified based on intervals (Figures 14 and 15). This analysis facilitated

identification of the magnitude and direction of changes within individual vegetation communities and provided insight to the processes operating and producing apparent change. The change classes were aggregated to represent either a decrease in brightness over time (<= -2.0 standard deviations from the difference image mean) or an increase in brightness over time (>= 2.0 standard deviations from the difference image mean). Approximately 50% of the change apparent in the visible bands corresponded to grassland and CSS communities, which showed equal occurrences of increase and decrease in brightness. Features 8 and 15 from Figure 18 account for much of the change area within the grassland; however, other isolated change features apparent in the visible composite change image corresponding to grassland and CSS communities (Figure 14) are most likely associated with seasonal/climatic related variations in phenology.

A greater amount of area was classified as change within the NIR difference image than the combined visible band difference image, and these apparent changes generally corresponded to more identifiable features. The sycamore class demonstrated a significant decrease in brightness within the NIR bands, as the 1998 imagery was flown earlier in the season than the 1996 imagery. Grassland and CSS represented a large percentage of the change in NIR. While a few features explain much of this apparent change, a large amount of the change can be attributed to variations in phenology. The mixed chaparral/CSS class showed a significant increase in NIR brightness between 1996 and 1998. Two patches of mixed chaparral/CSS accounted for all change in this class; one class was entirely comprised of the invading poison oak in 1998 (Figure 18, Feature 2) and the other is most likely influenced by an increase in herbaceous cover during the June 1998 image acquisition (Figure 18, Feature 9). Results from this analysis are consistent with results presented earlier. However, spatial correspondence analyses also provided new information about community specific changes.

These results illustrate that high resolution imagery provides a synoptic view of entire landscapes and that important information about habitat condition and change in condition can be derived from these image data sources. As with any semi-automated process, change detection results derived through image processing must be interpreted and human judgement used to translate data and image products into information. Some field reconnaissance is recommended to validate land cover changes and to determine the nature of those changes.

Change detection methods utilized here included basic steps such as image differencing and classification, which are available in all major image processing softwares. Changes in land cover during the two year period between 1996 and 1998 that were identified for the Sycamore Hills site included: trail widening, invasion of poison oak into a coastal sage scrub community, sedimentation within a grassland environment, and regrowth of vegetation in a previously used parking area and dirt road. Over longer time periods (i.e., 3 to 5 years), changes in vegetation community composition and health can be expected to be identified using the high resolution, multispectral ADAR imagery.

9.0 DISCUSSION AND CONCLUSIONS: COMPARATIVE COSTS AND BENEFITS (ADAR vs Conventional Methods)

A proper assessment of the costs and benefits of using ADAR compared to conventional mapping methods must evaluate the relative performance of the two methods. Performance is a function of many factors. Among the criteria that should be considered in evaluating performance are (1) the accuracy of the final map product, (2) the success with which the product meets the specific goals of the mapping application(s), and (3) the magnitude of resources (man-hours and dollars) expended to create the product. These elements are interdependent (e.g., accuracy is one criterion of success in meeting application goals) and are also influenced by many variables for both ADAR technology and conventional methods. The interactions and factors that influence these performance criteria make relative costs and benefits of both approaches difficult to quantify. The following discussion identifies the principal influences on performance and how they relate to each of the two methods.

9.1 Accuracy

Our previous study examining the feasibility of using ADAR to map coastal sage scrub and related habitats (Brewster et al., 1998) reported an accuracy of 93.4 ±-5% (95% confidence level) for vegetation classification at the plant community level. Such high accuracy, (though derived from a slightly undersized sample) is very encouraging, especially for a site with the vegetative complexity and rugged terrain of Sycamore Hills. In addition to a high degree of accuracy, the ADAR-based map for Sycamore Hills showed significantly greater detail and precision than the vegetation map of the same area produced as part of mapping for the larger County of Orange Central and Coastal NCCP Subregions (Jones and Stokes, 1993). The County of Orange map was produced by a team of field biologists performing photo interpretation on 1":400' color aerial photographs, with some field verification. The ADAR-based classification map was the result of focused mapping addressing only Sycamore Hills. While both products are landscape level vegetation maps, the ADAR-based map is site specific and the County map is subregional. The County's map is sufficient for identifying large-scale boundaries of plant communities for the purpose of designating subregional habitat preserves. The site specific map provides a level of detail that is potentially useful for local-level habitat management applications. The differences between the two maps are not only related to methods, but also differences in mapping objectives and applications. The discrepancies between them are more a question of precision, level of generalization and scale than accuracy. It is worth noting, however, that if the County had used ADAR data to create its subregional vegetation map, it would also have data with sufficient detail and precision to address site specific management issues.

In our other case studies we noticed discrepancies between the ADAR-based vegetation map and the map produced by field biologists using conventional methods (mapping in the field to ground-truth polygons drawn over 1:4,800 scale color aerial photographs). For both the Etiwanda site and Hidden

Ranch, the two pairs of maps show differences in size, shape and number of polygons, and in some cases differences in the plant community type assigned to similar polygons (see Figures 6 and 10 and 11 and 12.) There are several sources of error and uncertainty that can contribute to such discrepancies.

Mapper Subjectivity

A great deal of mapping activities, both in the field and in the lab, involve mapping decisions made by an observer. Observer bias can play a significant role in defining the size and shape of vegetative patches corresponding to a given plant community. This is especially true when the plant communities in question are similar in morphology and share species in common, as is the case in many southern California shrubland settings. At Etiwanda, for example, the two maps show remarkably good agreement in the identification and placement of most vegetation types. However, noticeable discrepancies are apparent in the boundaries between the three phases of Alluvial Fan Sage Scrub (pioneer, intermediate and mature). These discrepancies reflect differences in the observers' subjective responses to the composition and density of vegetation as observed on the two different image sources (ADAR and aerial photography) and/or in the field. Real, on-the-ground differences between the three AFSS phases (especially between intermediate and pioneer) are mostly a matter of gradation, and the delineation of boundaries between them is unavoidably arbitrary. This is also true for some of the plant communities mapped at the Hidden Ranch site (for example., the gradations between sagebrush buckwheat scrub, mixed sage scrub and sagebrush scrub). The subjective and often arbitrary nature of the kind of subjective decision-making related to vegetation categories can be reduced in part by agreement beforehand on operational definitions and rules for assigning plant community categories.

Mapper subjectivity can be a source of error or uncertainty in both ADAR-based mapping and conventional methods. However, ADAR-based classification provides a potential method for reducing observer bias that is not available to conventional manual classification techniques. The semi-automated classification procedure allows the operator to manipulate pixel size (through aggregation) and to predetermine the number of cluster classes. Because computer-assisted classification is interactive, the operator can codify operational definitions that delineate thresholds and boundaries between categories. The operator can then be assured that operational definitions related to community type recognition will be implemented consistently over the entire image. Moreover, such algorithmically defined categories can be implemented regardless of changes in personnel performing them.

Image Displacement

Another source of error is spatial displacement associated with the image (ADAR or aerial photograph) and/or the topographic data base used in georectification. Image displacement is believed to be a significant source of discrepancy between the two maps of Hidden Ranch.

Georectification is especially challenging at Hidden Ranch because of the highly variable terrain. While our RMSE for ground control points when matching raw ADAR data to the USGS DOQQ at Hidden Ranch was kept at or below 5 pixels (a very acceptable level for such varied terrain), the RMSE for random points throughout the rest of the image is certainly greater than 5 pixels and absolute errors (relative to the earth coordinate system) are likely even greater. The map produced by PCR for Southern California Edison (PCR, 1998) is subject to its own displacement errors originating from the aerial photographs used as a mapping base and whatever georeferencing procedures were performed to convert the map to GIS format. The magnitude of error associated with the PRC map is unknown and likely to be substantially larger than for the ADAR image maps. The two sets of errors associated with the two different maps very probably account for much of the discrepancy in polygon configurations.

Although image displacement is a source of error for both ADAR-based and conventional mapping, ADAR-based methods more readily facilitate error correction through application of softcopy photogrammetry and auto-registration. Conventional mapping, using an analog data base, has the ability to propagate image displacement error without facilitating its systematic correction.

Insufficient Field Verification

The lack of sufficient field calibration and verification is a very common source of error for both ADAR-based and aerial photography-based mapping. This kind of error plays a significant role particularly at sites where not all areas under study are accessible, such as at Hidden Ranch. This is also true of study areas that are unreasonably large for the selected mapping method, such as the County of Orange Central and Coastal subregional NCCP maps. An unaffordable number of man-hours would have been necessary to perform close-range field checking of the entire area. Conventional methods usually use color aerial photography as a base on which to map polygons delineating plant communities. The aerial photo can provide a means of locating oneself and natural features in the field. But it can also provide a data source for identifying vegetation. Depending on the number of man-hours expended and the size of the study area, field visits by biologists armed with aerial photos can be either a field mapping exercise with limited assistance provided by the reference photo, or a photo interpretation exercise with limited assistance from field visits. These two extremes illustrate the variability of conventional mapping methods.

Like all remote sensing techniques, ADAR also requires some degree of field verification. As described in the discussion on classification procedures (Section 7.0), site visits are essential to verify results of spectral signature classification and to refine discrimination between categories. To some degree, ADAR is subject to the same limitations as conventional field mapping. Areas not directly field checked (because of prohibitive terrain or excessive site size) risk being misclassified. Inaccessible areas field-checked only with binoculars can increase the probability of misclassification. For both mapping methods, field time is a significant source of costs. However, the semi-automated classification made possible by ADAR digital data provides an additional means of classification, thereby reducing the dependence on field observations. This translates to a reduction of in-field labor costs. Moreover, when using ADAR, field verification requirements tend to diminish over time when the same site is mapped repeatedly. This is because the initial investment in field time is to support the development of recognition procedures for site-specific vegetation categories. Once signatures for the resident plant communities have been established, changes in their extent, vigor or composition can be verified through focused field checks in limited areas of interest identified on the classified image. For monitoring applications, ADAR methods will show a decrease over time in costs associated with field verification. Field time can be limited with increasing efficiency to the testing of hypotheses related to important habitat management issues.

Accuracy of vegetation mapping is influenced strongly by all three of the above-cited sources of error. In most cases, the errors inherent in mapping vegetation can be more efficiently reduced using the ADAR-based methodology, largely due to the advantages of working in a semi-automated environment.

9.2 Achieving Mapping Objectives

As stated in Section 4.0, vegetation mapping should always be initiated with a clear definition of mapping objectives. Well-defined objectives identifying the intended use(s) of the data will greatly assist in the initial decision as to which mapping method is more appropriate. Historically, vegetation maps produced in southern California have been created to address project-specific environmental impacts, usually associated with the CEQA or NEPA process. These maps, produced by field biologists (usually botanists or generalists), typically identify resources according to a classification system, scale, level of detail and accuracy that reflect the generic issues relevant to development project approvals. In recent years (with the onset of multi-species habitat management programs like the NCCP) these maps have often been found to be marginally useful for habitat management. Some of the reasons for this include lack of standardized nomenclature, insufficient detail or scale of the minimum mapping unit, or in some cases simply failing to map the resources of interest. An example of the latter is illustrated in the mapping needs of a preserve manager interested in the habitat requirements of a specialized wildlife species. The preferred habitat of the California gnatcatcher, for example, does not correspond to any of the plant community categories adopted by the County of Orange and used in all of the County's NCCP-related mapping. The County's classification scheme was developed by botanists and reflects a floristic taxonomy that is useful for identifying plant communities, but not always appropriate for wildlife habitat management applications.

A feature of conventional mapping methodology is that once data have been mapped by the field biologist, the data's attributes are fixed; that is, attributes assigned in the field, once assigned, cannot be reattributed in accordance with an alternative taxonomy. Reclassification of field-classified data requires another visit to the field. A study site that is mapped by a botanist using a floristic-based taxonomy will require a second mapping if (for example) a map of gnatcatcher preferred habitat is desired.

By contrast, when applying image classification routines to digital image data such as ADAR, the classification process occurs subsequent to the image data collection. Because the ADAR-based identification and classification of vegetation types is not completely automated and not accomplished in real time (it is only the trained classification algorithms that subsequently parse the data), the raw, primary data (comprised of brightness values) remain available for reinterpretation and classification according to multiple, alternative taxonomies, allowing the data to serve multiple mapping needs. The potential for ADAR to provide information not inherently available in conventional data sources is dependent on the ability of ecologists and others to extract information other than the floristic categories that are the objects of most biological resource maps. This potential ability is largely unrealized, but is of great interest to researchers and managers alike. Management obligations of the NCCP are driving efforts to develop capabilities for mapping biological resources according to new taxonomies that classify attributes such as "habitat quality" or "habitat change." These new taxonomies call for new mapping technologies such as ADAR which do not bias the data collection process toward a single classification scheme and application.

Collection of raw image data is only one way in which ADAR provides the potential to meet more than one mapping objective in a single overflight. Because ADAR uses direct digital capture, data are immediately available for GIS formatting, facilitating image processing and other GIS-based analysis. It can be readily integrated with other spatially explicit data bases (such as digital elevation models, wildlife densities, hydrology and precipitation data) and spatially explicit models (such as a habitat suitability index or population viability model). ADAR data bases can be readily exported and shared in digital form, further facilitating their use in multiple applications. The ability to achieve mapping objectives for more than one application potentially makes ADAR a very cost-effective tool. Data sharing to meet multiple applications also has the potential to encourage cost sharing among multiple parties. These considerations tend to favor the use of ADAR when viewed in the context of long-term monitoring and multiple applications.

9.3 Expended Man-hours and Resources

As indicated earlier, typical costs of ADAR-based mapping are difficult to identify with reliability and consistency. The ADAR mapping, performed for this study was accomplished in a research context, introducing economic considerations that are not typical of costs to implement the technology. A best effort to identify costs is to provide potential ranges of expenditures for generic resources and tasks, and to identify the factors that influence both costs and benefits (such as those discussed above). Perhaps the most important principle to recognize is that costs of implementing ADAR are very context dependent. Costs and benefits are, of course, related to the specific application (or applications) and objectives, which will influence variables such as the extent of coverage, spatial resolution (pixel size), overlap of frames, and the desired accuracy of pre-processing and classification procedures. The cost of ADAR is not only in image acquisition, but in facilities and labor required for image processing and interpretation. Obviously, an institution such as the SCE GIAS Lab, with extensive GIS facilities and well-trained personnel, will be spared significant capital investment and start-up costs, while an organization with little or no in-house expertise in spatial data must make initial investments in proportion to its needs.

Costs associated with ADAR data acquisition vary widely depending on the timing of the flight, the ability to combine multiple acquisitions in one mission (cost sharing among multiple sites and/or users), market conditions and specific arrangements with the vendor. Acquisition costs can range from $500 dollars per square mile to as little as $100 per square mile. The cost associated with flying three sites in coastal Orange County and the Hidden Valley site was typically around $250 per square mile. Image acquisition costs are mostly a factor of aircraft mobilization costs and the extent of coverage. The per unit cost diminishes significantly as the size of the coverage increases, especially if the site can be covered in a single flight. Based on current, estimates from the vendor (Positive Systems, Inc.), as a general rule, at 1 meter per pixel spatial resolution, an area equal to about one to two USGS 7.5 minute quadrangle maps can be covered in a good flight day with the ADAR 5500 four band system. This equates to about 60 to 120 square miles, depending on terrain, the configuration of the site, and the sun angle and cloud cover specifications. One 7.5 minute quadrangle is covered by approximately 275-300 images at 1 meter per pixel resolution, assuming a side overlap of all frames of 35 percent. The cost for such a coverage might range from $12,000 to $15,000, which represents a one-day flight project.

For two meter resolution the number of images required diminishes by a factor of four. At 0.5 meter resolution the number of images increases by a factor of four. Additional flight days typically cost $6,000 to $8,500, depending on the location. Rough cost estimates for a hypothetical site are given below:

Area of site	300,000 acres (480 sq. mi.)
Assumed site dimensions	16 miles x 30 miles
Est'd. number of images (@1m resolution)	2,200
Est'd. flight lines (@ 1m resolution)	50
Est'd. number flight days	4
Rough cost estimate	$43,380
Est'd. number of images (@2m resolution)	550
Est'd. flight lines (@ 1m resolution)	25
Est'd. number flight days	2
Rough cost estimate	$22,170

These estimates should be considered to be very generalized. Actual costs can be influenced by many specific factors that would be considered in preparing more precise cost estimates for an actual project. Costs can also be reduced by cooperating with other organizations that require ADAR image data for other sites within southern California. Data collection can sometimes be confounded by weather conditions. Data capture for our study sites in coastal Orange County had to consider coastal fog, while the Etiwanda site was troubled by poor visibility from smog. Under acceptable weather conditions, a single mission could theoretically capture data for a site as large as the Central and Coastal NCCP Subregions in one day. A site of that size (ca. 853 sq. km) imaged at 1 meter per pixel resolution would probably approach a per unit cost of less than 20 cents per acre for the raw image data.

Labor costs associated with pre-processing and image classification are even more difficult to quantify. This is in part because of the broad range of options for pre-processing (in-house tasking, second or third party vendors). More importantly, the costs of orthorectification and mosaicking vary greatly according to the site terrain, the availability of high quality terrain data, and the number of frames per image. Labor rates are greatly dependent on whether personnel are in-house, full-time employees, or out-sourced contractors. In the long-term, labor rates can be expected to increase, both for field and laboratory personnel. Technology costs (software and processes) are expected to decrease as capabilities increase, also reducing the amount of labor required to perform technical tasks. Thus, costs related to technical tasks and data acquisition can be expected to decrease in the long-term, while rates associated with field tasks will increase. This scenario favors the use of ADAR technologies in the long-term. In both the long and short-term, the key to minimizing total cost is to limit in-flight aircraft operations and personnel time; the latter can particularly be reduced by limiting the amount of field activities.

9.4 Mapping Versus Monitoring

One of the most important considerations in deciding between ADAR and conventional methods is whether or not habitat monitoring is required. The goal of this research is to develop a data collection and analysis tool to support management of multiple species preserves. The requirements of management exceed baseline data collection and include repeated monitoring of habitat conditions. While many of the procedures described in this report apply to the creation of baseline maps, much of the power and cost-effectiveness of ADAR comes from its use in revising and updating baseline data. The development of baseline maps, as described in our Etiwanda and Hidden Ranch case studies, should be considered a one-time activity for any given site. The image-based change detection techniques described in the Sycamore Hills case study (Section 8.0) constitute actual monitoring. This latter exercise is different from baseline mapping, in its tasks, objectives and costs. The rather labor-intensive effort of creating an ADAR-derived base map is an initial investment that yields increasing benefits as the monitoring program is implemented.

9.5 Air Photos Versus ADAR

Because conventional field mapping and ADAR-based mapping use some of the same methods, it can be difficult to separate their differences. Both rely on some degree of field-derived ground-reference data, and both use a method of remote sensing. In the case of conventional mapping the remotely sensed data is usually analog color aerial photography. As indicated above, both methods are subject to the limitations and sources of error (as well as the benefits) associated with field reconnaissance, and the effectiveness of field data collection in both cases is highly dependent on the amount of time spent in the field. It is useful, therefore, to compare the relative benefits of the two image data sources alone, in a side-by-side comparison. A qualitative comparison of relative costs and benefits associated with habitat mapping and monitoring using conventional analog aerial photography versus ADAR is presented in Table 1. (Note that some of the cost advantages associated with the ADAR approach are reduced if the aerial photography is false color infrared and is scanned to generate digital image data.)

TABLE 1

AERIAL PHOTOGRAPHY VERSUS ADAR

Tasks	Relative Costs of ADAR	Benefits of ADAR
Data Capture		
Flight planning	Similar	Neutral
Airborne image capture	Slightly higher	In-flight brightness optimization
Digital image generation	Much lower	Direct digital capture
Pre-processing		
Orthorectification	Much lower	Directly amenable to softcopy photogrammetry
Registration to image map	Similar	Directly amenable to auto-registration
Mosaicking	Slightly higher	Directly amenable to auto-mosaicking
Radiometric normalization	Slightly lower	In-flight control & higher fidelity
Vegetation Mapping		
Hard copy generation	Much lower	True color & CIR; flexible scale and annotation
Initial field reconnaissance	Similar	Neutral
Image enhancements	Much lower	Greater latitude & flexibility
Image classification	Much lower	Directly amenable to pattern recognition routines
On-screen digitizing	Much lower	Directly amenable to on-screen interp/digitizing
Later field reconnaissance	Lower	Less field reconnaissance required
Final product generation	Similar	Directly amenable to generating raster maps

Accuracy assessment	Slightly lower	Expected higher accuracy means fewer samples
<u>Change Detection</u>		
Image differencing	Much lower	Higher fidelity
Change vector classification	Much lower	Directly amenable to identification of change classes
Hot spot identification	Slightly higher	Greater sensitivity and fewer artifacts
Field reconnaissance	Slightly lower	Fewer false detections to validate

9.6 Summary

The factors that influence costs and benefits of ADAR technology suggest that, in general, the use of ADAR is a cost-effective choice for habitat mapping when at least some of the following conditions are met:

- The need for mapping is repetitive, i.e., a need for frequently refreshed data (three to five years, or more);
- The application calls for landscape level monitoring, particularly monitoring that is specific, purposeful, and related to one or more hypotheses concerning changes in the environment;
- The data collection will meet the needs of multiple applications and/or parties;
- The resources to be mapped cover an area of medium to large size (probably at least a few hundred acres);
- The appropriate facilities and personnel are available to perform image processing functions;

In summary, there are several advantages to integrating ADAR-based mapping within a habitat mapping and monitoring program. First and foremost, the vertical imaging perspective from an airborne platform is the only practical means for conducting a wall-to-wall sample of habitat reserves and reserve systems. This, combined with the capability of synoptically viewing all canopy and exposed substrate features at nearly a single instant in time, is complimentary to the more precise and certain observations made at ground-level with lesser spatial coverage. Many of ADAR's benefits derive from the digital nature of its data, permitting image processing, enhancement and classification through computer-assisted procedures. The spatially-explicit, GIS comparability of the data facilitates its integration with other spatial data sets and use in spatially explicit models. The unclassified nature of raw ADAR data further facilitates its use in multiple applications requiring alternative classification scenarios. Finally, the repeatability of ADAR-related procedures (from data collection through pre-processing and classification) offers the potential for cost-effective monitoring of changes in habitat over time and in the long-term.

Perhaps the key to evaluating ADAR-based mapping and conventional mapping methods is to consider the two approaches as complementary, rather than mutually exclusive. Remote sensing techniques such as ADAR require, rather than preclude, conventional field methods for support. Field observations play an essential role in classification of ADAR data. Insights gained using ADAR's classification and change detection capabilities can inform and guide managers toward the most cost-effective ways to focus field studies. Under the best conditions, conventional field methods and ADAR technology can work together to achieve a higher level of efficiency than can be reached by either method used singly. A habitat management and monitoring program that integrates the several disciplines and methodologies available -- ADAR imaging, GPS, GIS, GIS-based modeling, field biology, landscape ecology, and conservation biology -- is likely to have the greatest success in achieving habitat management goals with a high degree of cost effectiveness.

Among the difficulties of determining and projecting costs of technologies is the dynamic nature of both the technologies and the associated industries. While the GIS and GPS industries continue to expand with the growth of their associated markets, the remote sensing industry has grown and matured more slowly. Finding commercial providers of specific image data and image processing services (e.g., orthorectification) and pinning down these service providers to give cost estimates can require much effort and perseverance on the part of prospective users. The increasing popularity of GIS (which relies on remote sensing for generating and maintaining data bases), the National Aeronautics and Space Administration's efforts to promote commercialization of remote sensing technology, and the planned launch of several commercial satellites with high resolution imaging and terrain mapping capabilities appear to be accelerating the maturation of the remote sensing industry. Remote sensing companies seem to better understand that if they are to be profitable, image data products need to be more accessible, provided in a form that is easy to use, and priced lower. San Diego State University (SDSU) is assisting NASA in its effort to build a sustainable remote sensing cottage industry by serving as one of four NASA Affiliate Research Centers (ARC) located at universities throughout the US. Southern California Edison and/or the California Energy

Commission may be interested in further exploring the commercial viability of habitat monitoring products and services by participating in the SDSU ARC program.

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11.0 GLOSSARY

Color Composite - A color image produced by assigning color to each image in a scene and superposing the result.

Coordinate System - Coordinate systems are necessary to specify the location of positions on both the earth and the map. In both cases we deal with two-dimensional systems. A mathematical conversion is applied to defined values based on a system of coordinates to transform three-dimensional coordinates to a two-dimensional surface.

Divergence Statistic - A quantitative measure of similarity/dissimilarity between groups of pixels that represent specific information class (called training sites); based on the variance and covariance statistics of these training sites.

Digital Orthophoto Quadrangle (DOQ) - A uniform scale photographic image in which the effects of camera tilt and terrain relief are removed through rectification. DOQQ - quarter quadrangle.

Feature Space Image - A graph of the data values of one spectral band against the values of another.

Geographic Information System - A system that provides an environment to compile, store, display and analyze spatially referenced data.

Georeferenced - Spatial vector or raster datasets that have been projected to real world coordinates.

Global Positioning Systems - a system to determine unknown locational positioning based on triangulation of satellites from known locations.

Ground Control Points - Image locations with known coordinates.

Image Rectification - geometrically correcting an image in terms of specific ground coordinate locations.

Image Registration - image to image georectification, resulting in higher geometric fidelity between images.

Mosaicking - the joining of two or more image frames or strips together to produce a single image.

Multispectral - More than one band on the electromagnetic spectrum at the same location.

Orthophotography - A digital orthophoto is the product of a process whereby an aerial photograph is scanned at high resolution and the locations and brightness values of the resultant pixels are computed to remove the effects of terrain as well as camera attitude and lens distortion at the time of exposure.

Orthorectification - A process used to geometrically correct image distortions caused by earth rotation and curvature, satellite motion, attitude and viewing perspective as well as relief displacement.

Panchromatic - A single wavelength band, black and white imagery.

Phenology - Leaf-out, reproduction, wilt, or other changes in the seasonal growth of plants.

Photogrammetry - The process of obtaining reliable spatial measurements from aerial photography and other remotely sensed images.

Radiometeric - The geometrical transfer of radiant energy from point A (the source) to point B (the receiver).

Remote Sensing - The acquisition of data about an object without being in direct physical contact with the object.

Retransformation - A step in the resampling procedure whereby registered output image pixels are temporarily repositioned over the input image in order to determine their new brightness value.

Root Mean Square Positional Error - The estimated error of positions on a map or image based on the square root of the mean square difference between a reliable reference and corresponding sample points locations on the map or image.

Spatial Resolution - The measure of the smallest distance between two objects that can be resolved (the two objects can be distinguished) by the sensor.

Spectral Bandwidth - A value range on the electromagnetic spectrum.

Spectral Signature - A set of data that defines a training sample, feature space object or cluster.

Spectral Resolution - A measure of the narrowest spectral feature that can be resolved by a spectrometer. Each pixel of imagery records light intensities for up to 288 different visible and/or infrared wavelengths.

Spectral Vector - The image brightness or digital number values in each spectral band for a pixel in a multispectral image.

Targets - Panels placed on unobstructed ground prior to photography collection used to create a discrete image point, with the intent of increasing horizontal accuracy.

Topography - Elevation.

Two-dimensional Array - A matrix.

Vector - The geometric representation of features. There are three vector types: points, lines and polygons. Only polygons have area. Points have location but no spatial area, lines have no width.

Videography - The use of a video camera for recording images.

12.0 PROCEDURES HANDBOOK

12.1 INTRODUCTION

This *Procedures Handbook* is a step-by-step guide to the image processing procedures essential to the creation and use of ADAR image data files for habitat management applications. These include procedures for:

♦ Image Registration

  • Georeferencing a digital image to a USGS 7.5 minute quadrangle

  • Georeferencing an ADAR image to a GIS data base

  • Georeferencing an ADAR image using GPS coordinates

  • Georeferencing an ADAR image using a DOQQ (Digital Orthophoto Quarter Quadrangle)

  • Registering one or more ADAR image to another ADAR image

♦ Creating an Image Mosaic of multiple ADAR image frames (Mosaicking)

♦ Creating a classification map of vegetation using ADAR image data

♦ Detecting habitat changes using ADAR image data

The procedures described here are based on methodologies employed in actual case studies of three different sites within Southern California Edison's service territory (Brewster, et al., 1999). The Handbook is intended to assist the staff of the Geographic Information & Analysis Systems (GIAS) Lab of Southern California Edison in implementing these procedures in order to integrate ADAR-based mapping and monitoring capabilities into SCE's multiple species habitat management programs. The level of instruction and guidance is therefore geared to the GIAS Lab as the specific user. It assumes a technical expertise with GIS files and software (particularly ARCINFO) and a rudimentary familiarity with remote sensing and GPS technologies. It also assumes a working knowledge of basic image processing principles and software, in particular with the ERDAS Imagine software. The procedures described can be performed almost exclusively using ERDAS Imagine, which is anticipated to be the GIAS Lab's image processing software of choice. It does not assume that image processing technicians have expertise in native plant communities, but assumes that such expertise is available to them.
As is true of most technologies, the best way to gain expertise is through hands-on experience. Much of image processing and classification involves an element of "seat-of-the-pants" judgement and decision-making on the part of the operator. Additional guidance and/or tutorial assistance can be obtained by contacting the preparers of this Handbook.

The Handbook is organized according to individual sections addressing each of the four basic procedures identified above: (1) image registration, (2) image mosaicking, (3) image classification, and (4) change detection. The Image Registration section first identifies the generic steps common to all five optional image registration methods. It also provides supporting information and helpful hints to guide the user in executing these steps. This is then followed by subsections identifying in very concise form the sequence of steps for each of the optional methods. The subsequent sections on mosaicking, classification, and change detection procedures, each describe generic steps to execute those procedures.

12.2 PRELIMINARY STEPS

As stated in the technical report (Brewster et al., 1999) the acquisition of ADAR imagery, its processing and subsequent analysis should be conceived and executed as part of a thoughtfully designed mission. The goals and procedures of the mission should be clearly defined before data acquisition, and should include identification of (1) mapping objectives, (2) methods, and (3) a project plan to implement selected methods. The goals and methods will in turn determine several key parameters associated with the raw ADAR data (e.g., spatial resolution, degree of overlap, solar angle specifications, etc.). They will also influence several variables associated with the image map derived through processing the data. Some of these image map variables are listed below (with likely choices made by SCE in brackets).

- map projection (with projection zone if applicable) [UTM];
- ellipsoid [Clark];
- datum [1983];
- precise upper-left coordinate for the origin of the bounding rectangle [specific to study site];
- equivalent ground dimensions (x and y) of the picture element (pixel) [1 meter];
- resampling routine used for interpolating or estimating digital number values for output grid (based on relationship to input grid) [nearest neighbor];
- ordering of wavebands [band sequential as blue, green, red, and near infrared bands]
- distribution media [compact disk].

12.3 IMAGE REGISTRATION

Image registration is the first step in the sequence of image processing procedures and is a necessary preliminary to mosaicking of multiple frames and the subsequent uses of ADAR image data. The objectives of image registration are (1) to georeference the ADAR image (i.e., project the data to real world coordinates), and (2) to ensure geometric fidelity of the new ADAR image with other ADAR images and/or with other spatial coverages.

As described in the companion technical report, there are several optional methods for registering ADAR images. These include:

A. Georeferencing a digital image to a USGS 7.5 minute quadrangle

B. Georeferencing an ADAR image to a GIS data base

C. Georeferencing an ADAR image using GPS coordinates

D. Georeferencing an ADAR image using a DOQQ (Digital Orthophoto Quarter Quadrangle)

E. Registering one or more ADAR image to another ADAR image

Each of these methods is described in detail as a separate case study in the technical report. They are executed using a few basic image processing procedures common to all of them. The basic procedures, which in sequence work to perform image registration, are:

1. Selecting ADAR frames

2. Selecting and using Ground Control Points (GCPs)

3. Transforming image coordinates

4. Evaluating the results of transformation

5. Resampling the image

6. Evaluating the georeferenced image

These six procedures consist of multiple steps that may slightly vary, depending on which of the optional methods for registration identified above is chosen. Some of the registration methods require specific steps not required for others. An example is the need to obtain GPS coordinates in optional method C. Ancillary procedures of this kind are described in the sections that follow, along with detailed procedural information and helpful hints to guide the user on their implementation.

12.3.1 Generic Steps for Image Registration

The six generic procedures for image registration are described below with explanatory information. Section 12.3.2 presents the same steps as they apply to the five different optional methods.

1) Select ADAR frames that cover the study area.

- Using image processing software, open and view individual frames to determine frame boundaries and select frames that cover the study area.

- If the flight lines were not flown from south to north, the source images may need to be rotated to the same orientation as the base image to be used for georeferencing.

2) Selecting and using GCPs

- Select a minimum of six well-spaced points that occur on both the unreferenced ADAR image and the georeferenced base image. Using the image processing software program, place GCPs on the digital image to be georeferenced and save the file. These are the file coordinates.

- First, select a GCP in the source image and then locate the same point in the destination image and place a GCP. For a second-order transformation, at least six GCPs are required (twice that number is recommended). Therefore, it is best to divide the image into six equal blocks and try to place at least one GCP in each block, although the spacing of GCPs depends on the terrain and the amount of accuracy needed for registration. Due to camera distortion and terrain displacement increasing outward, points that produce the best registration may be harder to find further away from the center of the image. The spacing of GCPs does not have to be equal across the image but a triangulated pattern of GCPs roughly equiangular works well. More open spacing is tolerable in flatter areas while denser spacing may be required in rougher/steeper areas. If the area has steep terrain and a DEM is not available for reference, a field visit to the site or to a comparable site can help the user associate actual terrain variability with its appearance on the imagery.

- The best GCPs are usually road intersections and corners of structures. This is especially true when using a GIS coverage as a base rather than another image. A GIS coverage lacks the detail of an aerial photograph or DOQQ, and often the only features that exist on both the source and destination are road intersections and structures.

- Selecting GCPs that co-occur in the overlap areas of adjacent source images will help reduce positional displacement between frames and will improve the final mosaic.

- After placement of all GCPs check that input and reference points are still matched pairs, located on the same feature on input and reference image, and that the control point error is as low as possible. During point placement, GCPs can jump or change location when subsequent points are added. Also the control point error for existing points can be adjusted upward automatically as new points are added, an indication of how the points work together to make the transformation.
- Save input and reference points for each image. They can be called-up as needed for making changes, adding or deleting points, and checking for common points in overlap areas of those images to be mosaicked. The addition of well-placed GCPs may help increase registration accuracy.

3. Transforming the Coordinates

- Transform the coordinates of the source image using the image processing software's menu options.

- The process of converting file coordinates from an image to be registered to a reference image coordinate system, utilizes transformations which employ polynomial equations. The order of the transformation is related to the complexity of the polynomial, the first order polynomial being the simplest to calculate. The first order transformation, also referred to as a linear transformation, corrects for distortion attributed to location and scale variations across the original image. The first order polynomial also corrects for distortion caused by rotation and skew. This transformation is useful for projecting original imagery to a planar map projection or for projecting one planar map to another planar projection. The second order polynomial transformation corrects for those linear distortions mentioned above and for warping, a nonlinear distortion. Second order transformations may be used for large areas, accounting for the Earth's curvature, and to correct for camera lens distortion. The first and second order transformations are the most commonly used while higher orders are reserved for notably distorted imagery.

- The variability of the topography will dictate the transformation order. First order transformations may be used in areas of little or no relief, while second or third order transformations should be applied in areas exhibiting extensive relief. The number of required GCPs increases with transformation order; the minimum required numbers are 3, 6, and 10 for first, second, and third order transformations, respectively. However, registration precision will improve with more GCPs and at least twice the minimum is recommended for second and third order transformations.

4. Evaluating Results of the Transformation

Use the RMSE (Root Mean Square Error) to evaluate the current transformation matrix. If the RMSE (Root Mean Square Error) is too high, adjust the GCPs by moving them slightly, using the GCP editor's interactive feature for guidance, making their location more precise and transform the coordinates again. Save the coordinate files when the RMSE is at an acceptable level.

- Obtaining an overall RMS error of 0.5 pixels for all ground control points is the goal during the GCP locating process. Local topography and/or inherent inaccuracies within the base image mosaic are likely to increase the overall RMS error for the transformation model.

- If the study site is relatively flat, a RMSE less than 1 should be achievable for all frames.

- When adjusting the GCPs to improve the RMSE, adjust the one with the highest error first and so on. Often, a lower RMSE can be achieved by moving one of the GCPs from its true matching location. Do not move a GCP to a false location to lower the RMSE. If the RMSE of a GCP cannot be lowered sufficiently, either delete or move both corresponding (source and destination) GCPs. Obtaining an acceptable RMSE can be a long, iterative process, and the time it takes to properly georeference each frame can vary dramatically.

- Save the GCP file when an RMSE less than 1 has been achieved.

- When georeferencing a photograph to a 7.5 minute quadrangle, expect the RMSE to be fairly high (>10). A RMSE of 10 is acceptable in this case due to the large area covered and the inaccuracies associated with coordinate determination from 7.5 minute quadrangles and the quadrangles themselves.

5. *Resampling the Image*

- Select a resampling method (nearest neighbor, bilinear interpolation, or cubic convolution), and using the image processing software's menu options, resample the image.

- Save the resampled image with a new file name.

- Three common resampling techniques are: Nearest Neighbor, Bilinear Interpolation, Cubic Convolution.

The following table describes the pros and cons of each method and when it is best to utilize each. In all the case studies detailed in this report, except one, the nearest neighbor technique was used. The exception was the imagery used for a date-to-date analysis at Sycamore Hills, which utilized the bilinear interpolation method. When deciding on a method, it is also important to consider the purpose of the image. For example, if an image is to be simply an object for viewing, a method like bilinear interpolation that smooths the data might be used, but if it is to be classified, a method like nearest neighbor that retains the original data values might be used. If there is uncertainty over which method is best, experiment with them and compare the results. In many instances, there may not be a detectable visual difference between the output images.

Method	Pros	Cons	When to Use
Nearest Neighbor	Retains original data values.	Some data values are dropped or duplicated resulting in stair-step effect.	When an image is to be registered prior to classification.
Bilinear Interpolation	Visually smooth output image. Spatially accurate pixels.	Smooths data values.	When a date-to-date comparison is needed.
Cubic Convolution	The mean and std. deviation of ouput pixels most closely resemble the mean And std. deviation of the input pixels.	Changes original data values by averaging.	When the spatial resolution of the imagery is being changed significantly.

6. *Evaluating the resulting georeferenced image*

Evaluate the positional accuracy of the newly georeferenced imagery against the base image.

- First, display the newly georeferenced image and overlay the base image coverage. Inspect the image to see how well it lines up with the base image. If it does not line up, note areas of displacement, and return to Step 2. Add or move GCPs in the area of displacement.

- Once the image lines up with the GIS coverage, display previously georeferenced ADAR images that overlap it to see how they line up. Expect some minor displacement at the edges of the images, because there is more distortion at the edges. In an area with a lot of relief expect more displacement at the edges of the imagery than at study sites with gentler topography.

12.3.2 IMAGE REGISTRATION PROCEDURES APPLIED TO FIVE OPTIONAL METHODS

Option A: Georeferencing a Digital Image to a USGS 7.5 Minute Quadrangle

1) Select well-spaced ground control points (GCPs).

   - View the digital image data to be georeferenced and the 7.5 minute quadrangle simultaneously.
   - Select a minimum of six well-spaced points that occur on both the digital image and the 7.5 minute quadrangle. Corners at road intersections serve as good ground control points. A minimum of six points is required for a second-order polynomial. Twice that number is recommended..
   - In a software program of choice, place GCPs on the digital image to be georeferenced and save the file.

2) Determine the coordinates for points selected on the 7.5 minute quadrangle.

   - SCE uses UTM NAD83 meters coordinate system, but most UTM coordinates on 7.5 minute quadrangles are in UTM NAD27 meters. Once the coordinates are calculated, they must be converted to NAD83 using a coordinate calculator software (available in Arcinfo and in Blue Marble Graphics software packages). These are the map coordinates.

3) Following the prompts or menu options of the image processing software, enter the map

coordinates in a column next to the corresponding file coordinates.

4) Transform the coordinates using the image processing software's menu options.

5) Use the RMSE (Root Mean Square Error) to evaluate the current transformation matrix. If the RMSE (Root Mean Square Error) is too high, adjust the GCPs by moving them slightly making their location more precise and transform the coordinates again.

   · When georeferencing a photograph to a 7.5 minute quadrangle, expect the RMSE to be fairly high (>10). A RMSE of 10 is acceptable in this case due to the large area covered and the inaccuracies associated with coordinate determination from 7.5 minute quadrangles and the quadrangles themselves.
   · Save the coordinate files when the RMSE is at an acceptable level.

6) Resample the image.

   · Select a resampling method (nearest neighbor, bilinear interpolation, or cubic convolution).
   · Save resampled image with new file name.

Option B: Georeferencing ADAR Imagery to a GIS Coverage

1) Select ADAR frames that cover the study area.

   · Open and view individual frames to determine frame boundaries and select frames that cover the study area.

2) Using image processing software, display the source image (unreferenced data) and the destination image (georeferenced base image).

   · If the flight lines were not flown from south to north, the source images should be rotated so that the top of the image is to the north.

3) For each frame, select well-spaced GCPs.

   · The best GCPs are usually road intersections and corners of structures. This is especially true when using a GIS coverage as a base rather than another image. A GIS coverage lacks the detail of an aerial photograph or DOQQ, and often the only features that exist on both the source and destination are road intersections and structures.

- Selecting GCPs that co-occur in the overlap areas of adjacent source images will help reduce positional displacement between frames and will improve the final mosaic.

4) For each frame, transform the data using a second-order transformation.

5) If the RMSE is too high, adjust the GCPs by moving them slightly, using the GCP editor's interactive feature for guidance, to make their location more precise and transform the coordinates again. Save the GCP file when an RMSE less than 1 has been achieved.

6) Resample each image.

   - Select a resampling method (e.g., the nearest neighbor technique).

   - Save resampled image with new file name.

7) Check the georeferencing of each frame.

   - First, display the newly georeferenced image and overlay the GIS coverage. Inspect the image to see how well it lines up with the GIS coverage. If it does not line up, note areas of displacement, and return to the previous step. Add or move GCPs in the area of displacement.

   - Once the image lines up with the GIS coverage, display previously georeferenced ADAR images that overlap it to see how they line up. Expect some minor displacement at the edges of the images, because there is more distortion at the edges. If the images do not line up well, determine which image(s) have the most error and repeat step 5.

Option C: Registering with GPS Coordinates

1) Select GCPs for GPS data points.

   - Display each image and search for inherent scene features that are easy to locate in the field, such as road intersections, the juxtaposition of concrete structures and natural features such as isolated rock outcroppings.

   - Try to select GCPs that are well-distributed throughout the image, although this can sometimes be difficult. Place GCPs on the image and save the file to be used in the georeferencing process.

- In most "natural" areas, there are portions of the imagery that contain few, if any, inherent and distinct scene features that can be reliably located and used as GCPs. If this is the case, markers, which can be located on the imagery, must be placed in the field prior to the overflight. Large, white plastic garbage bags staked to the ground will work. They should be arranged in a large cross pattern and placed at least as wide as a pixel (e.g., 1.0 meter) and extend in length up to 5 to 6 pixels (e.g., 5 to 6 meters for 1.0 meter pixels). Place them in the field the day before or the morning of the overflight, collect coordinates for them using GPS, and retrieve the markers from the field as soon as possible. Leave a stake or rebar at the center of the marker if you want to return to the site at a later date, or in case problems with the GPS data require re-collection of points.

- As a general rule, collect five or more GCPs for each frame. For a second-order transformation, you will need a minimum of six per image, but remember in areas where the images overlap, a GCP can be used for both images. It is best to collect more than are needed and use the reserve GCPs to assess the accuracy of the frames or georeferenced mosaic.

- Search for points with known coordinates, i.e., USGS benchmarks within the study site. Recording these points in the field with the GPS will provide a good accuracy assessment of the GPS data.

2) Collect GPS coordinates for GCPs using a differential GPS receiver.

- Before collecting data, find a reliable base station. Base station data can be purchased from SOKKIA who operates base stations in both San Diego and Orange County. Free base station data can be obtained via the Internet from the Southern California Integrated GPS Network (SCIGN) and from the Continuously Operating Reference Station (CORS). For more information about these data, see the 1998 report, "An ADAR Based Habitat Monitoring System" (Brewster et al., 1998, p. 10 - 11) or visit the Scripps Orbit and Permanent Array Center's (SOPAC) web site (**http://lox.ucsd.edu/).** GPS base station data can be downloaded from this site.

- Generate image enlargements on a large format ink jet plotter for each frame, marking the GCPs selected in step 1.

- Locate GCPs in the field and record their location using GPS. Make sure the data collection interval (epoch) and the time spent recording each GCP are sufficient. Depending on the accuracy of the GPS unit and the distance from the base station, more or less time can or should be spent collecting data for each GCP. A centimeter level GPS processor can be used, but decimeter level accuracy data may be sufficient, depending on project requirements. More accurate locational data can be obtained by setting up a tripod to hold the GPS unit in a stationary position over the GCP and collecting data for longer periods of time. Consult your GPS manual for more specific information.

3) Download and Process the GPS data.

· In most cases the base station data must be converted to a format that is compatible with the GPS data collected in the field. Most GPS software packages perform this function.

4) Assess the accuracy of the data.

· Accuracy of the GPS points can be assessed from RMSE values accompanying the processed GPS data (normally provided as a by-product of data processing), and by testing against points with precisely known coordinates (e.g., benchmarks).

Option D: Registering with a DOQQ

1) Select ADAR frames that cover the study area

2) Display the source (ADAR) and destination (DOQQ) image(s).

3) For each ADAR frame, select well-spaced GCPs.

· Select at least six GCPs distributed across the image.

4) Transform the data using a second-order polynomial.

5) If the RMSE is too high, adjust the GCPs by moving them slightly to make their location more precise and transform the data again.

· After placement of all GCPs check that input and reference points are still matched pairs, located on the same feature on input and reference image, and that the control point error is as low as possible. During point placement, GCPs can jump or change location when subsequent points are added. Also the control point error for existing points can be adjusted upward automatically as new points are added, an indication of how the points work together to make the transformation.

- Save input and reference points for each image. They can be called up as needed for making changes, adding or deleting points, and checking for common points in overlap areas of those images to be mosaicked. The addition of well-placed GCPs may help increase registration accuracy.

6) Resample each image.

   - Select the resampling method.

7) Check the georeferencing of each frame.

   Evaluate the positional accuracy of the newly georeferenced imagery against the DOQQ.

Option E: Registering to Existing ADAR Image Maps

1) Open the non-registered imagery and the image map in viewers and position adjacent to each other.

2) Place well-distributed GCPs upon features common to both the image map and the non-registered images.

3) After placing all GCPs and deriving a satisfactory RMS error, apply the transformation and resample the individual image scenes.

4) Evaluate the positional accuracy of the newly georeferenced imagery against the pre-existing ADAR image.

12.4 MOSAICKING PROCEDURES

After the new ADAR image has been registered, individual registered image frames are mosaicked together to create an image map.

- First, to improve the appearance of the mosaic, trim some of the overlapping areas from each frame. This step is optional and should be performed with a specific purpose in mind, e.g., to delete coverage outside the study area or extraneous areas that exhibit distortion at the edge of the image. Options for specifying extents and portions of images include: (1) use of cutlines to specify where breaks occur between the values of two or more overlapping images; (2) use of areas of interest (AOIs) or polygons to limit the extent contribution of individual input images, or (3) a percentage of overlap to be trimmed can be specified.

· Add the frames to the image processing software's mosaicking viewer. Select a frame overlap method, and combine. The appearance of the mosaic can vary depending on the order in which the frames were specified. Experiment with different combinations to find the best spatially and spectrally matched mosaic. Several approaches to joining overlapping images are available (see discussion below), and the best joining method depends on the application of the finished mosaic.

There are several different types of intersections that can be used to join and overlap images when creating image mosaics. The overlap function specifies the method that will be used to reduce the multiple layers of image data from the overlap portions of the imagery into one layer. Intersections at overlap areas might be made by simply overlapping one image over another and having the pixel values of the top image become the mosaic's data values. This works well when the registration is very good and differences in brightness values along the boundaries between images are not critical or have been radiometrically corrected. Averaging is another kind of intersection option that can be used when registration and radiometric balance are very good. Using the averaging technique, brightness values of the top and bottom pixels are averaged and that value becomes the data value for the overlap area. Intersections that designate the minimum or the maximum values to become the data values for overlap areas are two options that can be used to influence the evenness of radiometric quality across some mosaics. The feathering intersection type uses a distance weighted averaging that weights top and bottom pixels equally at the center line of the overlap and lessens or increases the influence of the top or bottom pixel moving away from the center line in the direction of one image or the other.

The table below describes the pros and cons of each of the four common methods of image intersection and when it is appropriate to utilize each. In all case studies outlined in the technical report, the feathering option was used. In most cases, the feathering option is a safe bet and will usually produce the best overall results due to the radiometric differences between ADAR frames. If there is doubt as to which method is best, experiment with different methods and compare the pixels along the seams visually and spectrally. It is also import to note that the percentage of overlap trimmed from each frame and the order in which the frames are added to the mosaicking viewer will make a difference in how the mosaic looks. Selection of a mosaicking method and its execution should be considered a case-by-case interactive process, because each set of ADAR data has its own unique characteristics (attributable to time of year, time of day, time between flight lines, the camera, airplane angle and altitude differences between flight lines, etc.,).

Method	Pros	Cons	When to Use

Overlap	Maintains true data values	Differences in brightness values and mis-registration between frames are obvious.	When registration is very good and differences in brightness values along the seams are not important.
Averaging	Uses the average brightness value from all overlapping frames thus creating smoother seams.	Large differences in brightness values between frames will create pixels whose brightness values do not resemble pixels within the same classification category outside the overlap area and misregistration between frames is obvious.	When registration is very good and when the frames are radiometrically balanced.
Minimum or Maximum	Maintains true data values.	If images are not radiometrically balanced, one frame will dominate the other and create a visible seam.	When even brightness values along the seams are desired.
Feathering	Uses brightness values from all overlapping frames and calculates the distance weighted average thus creating smoother seams.	The most computationally intensive method.	When frames are not radio-metrically balanced and registration may be slightly shifted. Creates a smoother image.

The feathering option may be preferable with many applications because the averaging procedure uses information from all image data inputs and the use of weighted averaging reduces hard edges and results in seamless, visually appealing image mosaics.

12.5 VEGETATION CLASSIFICATION PROCEDURES

1) In the software program of choice, run an automated, unsupervised classification procedure on the image mosaic.

    · Specify an input raster file (the mosaic to be classified) and an output file. Depending on the software used, a signature file may need to be specified as well.

    · If more than one choice is available, choose a clustering method. ERDAS Imagine, for example, only offers one choice, ISODATA (Iterative Self-Organizing Data Analysis Technique), which is a standard method offered by most image analysis software packages. The method uses the minimum spectral distance to form clusters, and begins with random cluster means or the means of an existing signature set.

    · Select the number of classes. For the first clustering, use a fairly low, round number. This first pass at classification is designed to familiarize the user with the data and get a general idea about how the data are clustering.

    · There are other options that can be selected such as: skip factor, number of iterations, and the convergence threshold. For the most part, the user can safely apply the defaults. For both study areas, the default skip factor of 1 in both the x and y axis was used, the default convergence factor of 0.95 was used, and the number of iterations was increased from the default of 6 to 9. Increasing the skip factor will increase processing speed, but will skip pixels, thus decreasing accuracy. The convergence threshold is the maximum percentage of pixels whose cluster assignments can go unchanged between iterations. The iterations option is the maximum number of times the algorithm should recluster the data. Increasing this number increases the processing time, but might increase the accuracy.

· Specify areas to be masked out of the classification. If there are portions of the image map that don't need to be classified, the user can specify a vector coverage that excludes these areas. In ERDAS, this is called an area of interest (AOI). Masks can be very useful if large areas that will ultimately be classified into one category (e.g., developed) exist within the imagery, but lack one distinct spectral signature that easily distinguishes them from surrounding areas. Using masks can save both time and frustration.

2) Label the image derived from step 1.

· Open the image created in step 1. It will appear in gray scale.

· Before a classification is labeled, the user must have a clear idea of the classes and level of classification desired (i.e., level of detail). This is among the set of parameters determined during the project planning stage.

· Use the raster attribute editor to change the colors of the classes and label them. If the user lacks knowledge about the site and has no ancillary data, labeling can be difficult. If the image cannot be labeled immediately, then use a color slice to assign color to the classes. This will quickly reveal how the data are clustering.

3) First field visit to label classifications.

· Before the field visit, print out large color plots of both the unclassified ADAR and the classifications from step 2.

· Drive and walk the site, making labeling clusters and making notes regarding vegetation class boundaries.

· If there is an existing vegetation map, check it for accuracy.

· If a quantitative accuracy assessment is desired, use a GPS to record the locations of vegetation classes selected by a biologist. The selected points should be representative of the classes of vegetation at the site, be well distributed throughout the site, and have at least three samples for each vegetation class.

4) Repeat step 1, refining the technique based on knowledge gained during the field visit.

- Repeat the unsupervised classifications performed in step 1, increasing the number of classes based on what was learned in the field.

- If there is some trouble defining classes, this is the time to experiment with the data. As stated previously, pixels can be aggregated if there is too much detail, or contrast stretching can be applied to the imagery to try to differentiate classes that are spectrally similar. Contrast stretching expands the range of the original brightness or digital number values of the image data to make use of the full dynamic range available (usually 0 - 255). Another option is to break the study area into smaller, more manageable sections and classify each separately.

5) Second field visit.

- Before the field visit, print out large color plots of the classifications derived from step 4 and bring the plots created for the first field visit as well.

- The purpose of this field visit is to draw vegetation class boundaries if necessary and address unresolved classification questions.

6) On-screen interpretation and digitizing to produce a final vegetation map.

- First, create a blank GIS layer or ArcView Shape file.

- In the image processing or GIS software package of choice, display both the image mosaic as a false color composite and the color-coded classification created in step 4.

- Use a line tool to create vegetation class boundaries. Utilize the plots that were taken to the field and labeled in conjunction with the on-screen images to help determine class boundaries. Using the unclassified and classified ADAR image maps in combination as aids in detecting class boundaries.

7) Turn vector product created in step 6 into a GIS layer.

- When the on-screen digitizing is complete, use a GIS package to create polygon topology, correct errors in the coverage (unclosed polygons, dangling arcs, etc.,), create polygon attributes, and label the polygons. Arc/Info software was used for our case studies.

8) Qualitative and/or quantitative accuracy assessment.

- The new vegetation map can be qualitatively assessed for accuracy by a return visit to the study area to check that polygons are labeled correctly and their boundaries drawn accurately.

- A quantitative accuracy assessment can be achieved by comparing vegetation sample points collected with a GPS to corresponding polygon vegetation labels. Most image processing software packages include accuracy assessment capabilities, although the calculations can be easily set-up and performed in any spreadsheet software package (e.g., Microsoft Excel).

12.6 CHANGE DETECTION PROCEDURES

Change detection using multitemporal image data involves comparing image brightness values or derived products such as vegetation indices and classification products between two or more time periods. The underlying assumption is that changes in land cover results in changes in brightness values and/or derived products from the image data and therefore, can be detected using remote sensing instruments. The sections below describe two different methods for radiometric normalization (an optional preliminary step to change detection) and four alternative methods for change detection.

12.6.1 Radiometric Normalization

A useful first step that is performed prior to comparison of brightness values is radiometric normalization. Radiometric normalization procedures are applied in an attempt to standardize image brightness values and minimize differences that can result due to varying atmospheric conditions, solar illumination conditions (i.e., solar position), sensor settings (aperture, shutter speed, detector sensitivity/gain), etc. Such normalization is performed for one or more image dates relative to a base image, such that like waveband images are referenced or radiometrically registered to an image captured for the same wavebands as the reference or base image. Normalization procedures should be applied to individual image frames prior to mosaicking. Normalizing the image data allows for more direct comparison of brightness values between dates. However, radiometric normalization should be considered as an optional processing step that achieves relative, but not necessarily absolute normalization between image dates. Useful enhancements of land cover changes can be achieved without having first normalized multitemporal images, particularly when post-classification comparison approaches (described below) are utilized as a change detection procedure.

Pseudo-Invariant Features Methodology

The first method is the pseudo-invariant features approach where brightness values from one image are aligned with another using a linear offset function. The function is determined by selecting brightness values associated with multiple invariant features from the two dates of imagery. Such features are radiometric calibration points that are considered to have nearly constant spectral reflectance for the multitemporal image pair being normalized to one another. Normally the scene characteristics associated with these calibration points are unvegetated, man-made features, rock outcrops, or exposed soil and sediment. Because the features are "invariant," differences in mean and variance (expressed in the linear offset function) between the samples from the two dates are used to calibrate a linear transformation for adjusting all image values from one date so as to match values from a reference year.

1) Identify multiple pseudo-invariant features that are common to both the reference imagery and the imagery to be normalized. These features can vary in size from a few pixels to a few hundred pixels and again, usually are unvegetated. Pseudo-invariant features containing multiple pixels (50 to 200) are recommended so as to reduce the high frequency variation that may be found in a small sample of image data.

2) Use areas of interest (AOI) tools to delineate sample polygons from within the full extent of the pseudo-invariant features and to extract the statistical information (signatures) from those AOIs. Perform this step to extract samples for both the reference and the non-normalized imagery. It is recommended that 15 to 30 pseudo-invariant features be identified per frame in order to develop the relationship between the radiometric values of the reference and non-normalized image data.

3) Extract the mean values from the pseudo-invariant feature samples for both data sets (reference and non-normalized) and export these values into software that can perform simple linear regression. The Microsoft Excel spreadsheet software package can perform this function and was used for the example in this report.

4) Perform a simple linear regression using the sample mean values from both data sets and obtain the least squares, linear relationship between the two data sets. Verify that mean values from like samples (identical pseudo-invariant features) are being used to develop this relationship.

5) Obtain the equation for the least squares line that describes the relationship between the two data sets. This can be accomplished in Excel by plotting the values from the two data sets against each other using the scatterplot function, right clicking the mouse on one of the data points, and selecting add trend line (linear), and display equation on chart. Be sure that the reference data values are plotted on the Y-axis and the non-normalized data values are

plotted on the X-axis.

6) Use the equation provided by the least squares relationship to convert the non-normalized data values to normalized values that match the reference data values. This is accomplished by multiplying the non-normalized values times the slope of the least squares line and adding the y-intercept value.

7) Repeat the above steps for each waveband image.

Histogram Methodology

A second method of radiometric normalization is a type of histogram matching approach. In this approach, rather than matching brightness values from several pseudo-invariant features, the digital values for all pixels representing the study area were extracted and the mean and standard deviation values of the distributions for each image date were matched to those values of the reference year. The assumption in this approach is that "on average," the land cover did not change between the two dates. Therefore, the mean and standard deviation of the image brightness values should be nearly the same for both dates and any changes will result in a deviation from normalized values between dates.

1) Use image masking procedures to set all image values not associated with the study area to a value of zero; and recalculate the image statistics ignoring zero values. This step is optional and may be performed to reduce the total variation of the scene that is to be normalized.

2) Extract the mean and standard deviation values of the image pixels with non-zero values (masked) in step 1, for both the reference and the non-normalized image data.

3) Using the mean and standard deviation values from both data sets calculated in step 1, convert the non-normalized image data to normalized image values that match the reference data.

   To perform this task, apply the following equation to the non-normalized image data:

   $$((NN-mean_{NN})/stdev_{NN}*stdev_{R})+mean_{R}$$

where:

NN = the non-normalized data
$mean_{NN}$ = mean of the non-normalized data
$stdev_{NN}$ = standard deviation of the non-normalized data
$stdev_{R}$ = standard deviation of the reference data
$mean_{R}$ = mean of the reference data.

4) Repeat the above steps for each waveband image.

12.6.2 Change Detection Methods

Several methods of change detection are available. These methods include:

- differencing of the individual ADAR 5500 spectral bands;
- differencing of the Normalized Difference Vegetation Index (NDVI);
- differencing of local spatial variation measures of waveband images (image texture);
- differencing of local spatial variation measures of NDVI images (NDVI texture);
- change vector classification; and
- multitemporal image classification comparisons.

Each of these methods may provide different information on land cover change and each method requires that different image processing procedures with varying complexities be applied. Subsequent processing includes:

- differencing of the brightness values;
- differencing of derived products having continuous values; and
- comparison of derived products containing categorical information.

Spectral Image Differencing

1) Subtract the earlier date image from the later date image. ADAR 5500 data are provided in integer, or also called, unsigned 8-bit format (values range from 0 to 255). Differences image values should be output as signed 16-bit so that difference values can range from a possible –510 to +510. While this is the maximum possible range, data values will most likely range between –100 and + 100 and can be specified as signed 8-bit (maximum range –127 to + 127). Additionally, values can be increased by 100 (add 100 to all) and specified as unsigned 8-bit; in this scenario, a value of 100 represents no change. Some image processing software packages only handle unsigned 8-bit data values.

2) Group difference images into interval classes by using mean and standard deviation statistics. Interval classes provide more general information on the magnitude and direction of differences. For example, difference image values that are two standard deviations above the mean and greater represent a change from lower values in time one to higher values in time two (such as land cleared for development).

3) Determine the classes of interest. Individual classes will correspond to a particular range in difference values.

4) Identify the mean and standard deviation values of the difference image.
5) Use conditional statements in image processing models to set continuous input values from ranges identified above to thematic output, where pixel values represent the difference class.

6) Apply 5 x 5 focal majority windows twice (repetitive runs) over the interval class image to remove (re-classify) isolated pixels and spatially generalize the resultant change interval class image.

Difference images were created for individual wavebands. These single band difference images were "stacked" into a multiple band difference image and the combined information was exploited.

Change Vector Classification

1) Stack multiple difference images into a single image. These difference images may include individual waveband, vegetation index (e.g., NDVI, described below), texture difference image, or other continuous value (i.e., not categorical variable) images, as discussed below in greater detail.

2) Classify the multiple band difference image. Input this image into the unsupervised image classification routine (e.g., ISODATA) and specify the number of desired cluster classes to be output. A single band, thematic image with the specified number of classes will be created. In addition, a file with signatures for each of the output classes may be created by the unsupervised classification program. This signature file is useful for determining the types of changes identified by the individual classes by plotting class means onto band to band scatterplots (called feature-space).

3) Assign class labels to the cluster classes of the thematic image using information about the type of change (e.g., increase in a vegetation index over time would indicate increased vegetation cover), and/or knowledge derived from field experience gained before or after performing change vector classification, and/or from on-screen analysis of the multitemporal ADAR data set.

4) Apply 5 x 5 focal majority windows twice (repetitive runs) over the interval class image to remove (re-classify) isolated pixels and spatially generalize the resultant change interval class image.

NDVI Differencing

The Normalized Difference Vegetation Index (NDVI) provides information on vegetation leaf area, biomass of photosynthetic materials, and condition. The NDVI is calculated for each pixel as (NIR-Red)/(NIR+Red), where NIR represents digital number, or spectral radiance, or spectral reflectance values for the near-infrared waveband and Red is the like quantity for the red waveband. The image differencing approach can be applied to the individual NDVI images to highlight changes in vegetation condition. Difference images are generated with multitemporal NDVI images. Similar to difference images from individual spectral bands, NDVI difference images are single band, continuous gray-scale images where high or low departures from the mean tend to represent a higher magnitude of change in vegetation abundance. As with waveband difference images, NDVI difference images are grouped into interval classes of change.

Texture Differencing

Image texture refers to a measure of local brightness variation around an individual image pixel. A measure of variation can be derived by passing a window over each pixel in the image (usually a 3x3 or 5x5 window), calculating the variance of the pixels falling within that window, and outputting the variance measure into the pixel that corresponds to the center of the moving window. This moving window is passed over all pixels within the image, the variance around each pixel is calculated, and an image containing only measures of local variance for each pixel is output. This output image is referred to as a texture image because the output pixel values indicate the magnitude of brightness texture (or local heterogeneity) around that image pixel. Because the calculated variance is a local measure (only provides information on pixels near the pixel of interest), texture images are most useful for identifying abrupt changes in brightness such as a trail cutting through a patch of chaparral. Therefore, texture difference images may be useful for identifying changes in features that have abruptly brightness variations over short distances (e.g., erosional features and trails).

NDVI texture differences can also be created in the same manner as the texture images described above, with the exception that texture is calculated using NDVI values rather than the original multispectral brightness values. NDVI texture images are most useful for identifying local changes in vegetation cover.

SUMMARY

BACKGROUND

This report presents results of research to develop methodologies for mapping and monitoring critical California habitats using ADAR (Airborne Data Acquisition and Registration), a high-resolution airborne multi-spectral imaging system. The study is part of a long-term research program initiated by Southern California Edison as early as 1995. Southern California Edison's California Habitat Evaluation Research Program began with research to apply ADAR technology to monitoring coastal wetland habitats (Phinn et al, 1996). In its second stage, the program extended the use of ADAR's imaging capabilities to the mapping of coastal sage scrub, a habitat of special interest in Southern California and the subject of the State of California's ambitious Natural Communities Conservation Program (NCCP). Research in this second stage demonstrated that ADAR can be used to identify and map components of the coastal sage scrub community, as well as related communities such as chaparral, grassland, sycamore woodland, etc. (Brewster et al., 1998). The research described in the present report, conducted during the period from June 1998 through June 1999, represents the third stage of the program, with the goals of further enlarging the mapping and monitoring capabilities of applied ADAR technology and of bringing the technology closer to operational (rather than experimental) use. The specific objectives of stage three research are described in detail in the section that follows.

The fourth stage of the California Habitat Evaluation Research Program, designed to follow upon the now complete third stage, includes goals of adding conifer forest and related woodland communities to the repertoire of habitats that can be mapped effectively using ADAR, and making time-sequence (multi-year) monitoring fully operational.

The overall goals of the research program, and of the present study in particular, serve several needs. Mapping and monitoring of critical habitats is a vitally important function to managers of habitat preserves. Development of ADAR technology as a mapping and monitoring tool therefore supports the conservation goals of the State's NCCP. As a pioneering "habitat-based" conservation program, the NCCP is just now entering its implementation phase, and the newly entrusted managers of participating preserves recognize a need for new, cost-effective technologies to assist their efforts (Almanza, 1998). The availability of ADAR technology to support management of preserves will not only assist Southern California Edison, as a permittee with coastal sage scrub habitat in NCCP preserves, but can also assist other NCCP participants (such as San Diego Gas & Electric) as well as the regulatory public agencies (California Department of Fish & Game and U.S. Fish and Wildlife Service). Mapping and monitoring tools also have the potential to serve conservation needs within California and beyond that are outside the regulatory purview of the NCCP. As multi-species and habitat-based conservation programs proliferate in California, the demand for cost-effective habitat management tools will increase. As a rapid, efficient method for collection of digital, landscape-level data, ADAR has the potential to provide the real-time data necessary to drive monitoring and management tools such as RAMAS and other meta-population models. Development of mapping and monitoring tools through this research lays the groundwork for a wide range of capabilities that comprise the toolbox for managing California's legacy of habitat preserves.

OBJECTIVES

The objectives of research conducted in 1998-99 are:

1. To enlarge the mapping capabilities of ADAR methodologies to include numerous habitat types not previously established within the technology's repertoire. The additional habitats (several dozen) were studied through two new study sites, each offering a range of plant communities not found within previously studied sites. These two sites, Hidden Ranch (or Black Star Canyon) and the Etiwanda Alluvial Fan, were each selected for the diversity and the critical character of their habitats. Among the new plant communities studied at the Hidden Ranch site are:

    Chamise chaparral
    Maritime Chaparral-Sagebrush Scrub
    Purple Sage Scrub
    Southern Willow Scrub
    Needlegrass Grassland
    Coast Live Oak Riparian Woodland
    Coast Live Oak/Chamise Chaparral Woodland

    Newly studied communities provided by the Etiwanda site include:

    Alluvial Fan Sage Scrub (Pioneer, Intermediate and Mature phases)
    Alluvial Fan Chaparral
    White Sage Scrub
    Ceonothus Chaparral
    Walnut Woodland

    The application of ADAR methodologies to such a diverse range of plant communities allowed our research team to better ascertain the limits and capabilities of ADAR as a mapping tool and some of the conditions that influence ADAR's efficiency.

2. To examine the feasibility of detecting changes in habitats over time, based on multi-date ADAR imagery. Research of ADAR's change detection capabilities included developing procedures for locating differences in images from one year to the next and identifying the relationship of image differences to actual changes on the ground. Image differencing requires co-registration of year-to-year imagery and employs "differencing" procedures. This study examined the relative success of several differencing procedures. The Sycamore Hills site in coastal Orange County which we have mapped using ADAR in previous years was our study site for these procedures.

3. To describe the relative costs and benefits of using ADAR for mapping and monitoring compared to using conventional mapping methods. Habitat mapping by conventional methods usually involves field surveys conducted by one or more biologists, typically labeling polygons corresponding to plant communities hand drawn over black and white or color aerial photographs. Our study identifies conditions when it would be more cost-effective to employ ADAR to map vegetation, the special capabilities of ADAR not available through conventional methods, and the factors that influence the relative costs and benefits of both methods.

4. To synthesize the procedures employed in the various tasks and case studies of this research, and to present them in a well-documented format to be used as a Procedures Handbook by Southern California Edison's GIAS Laboratory staff. The purpose of the Procedures Handbook is to enable staff to learn and execute the procedures developed through this research for the acquisition, post-processing and classification of ADAR data in order to produce habitat maps.

The multiple objectives of this research lend the project a complex aspect. It is a research project, because of the research required to develop and test refined procedures. It is a demonstrations project in its application of procedures to multiple study sites. It is a comparative analysis that addresses relative benefits of different methodologies. And it is a documentation process designed to transition newly developed procedures into an operational phase.

METHODS

Habitat Mapping

Three different methods of converting ADAR image frames to image maps were examined to compare their relative cost-effectiveness: (1) in-house image processing: (2) processing by the vendor; and (3) processing by third parties. The products of each of these procedures were evaluated for precision (root mean square error) as well as their cost and turn around time in obtaining the product. The use of three different study sites provided the opportunity for case studies to test and evaluate five different in-house methods for in-house image registration and mosaicking. These include (1) registration and mosaicking to a GIS data base; (2) registration and mosaicking with GPS coordinates: (3) registration and mosaicking with a digital orthophoto quarter quadrangle (DOQQ); (4) registering to existing ADAR image and mosaicking; and (5) registering and mosaicking using Orthomax software.

Habitat mapping at the two new study sites (Hidden Ranch and Etiwanda Alluvial Fan) was performed using the same general methodology used previously for the Sycamore Hills site and described in Brewster et al., 1998. In the case of Hidden Ranch, ground reference vegetation data was provided in GIS form prepared under separate contract for SCE by a biological consultant (PCR, 1998). Data for the Etiwanda site was developed for this study by consulting biologist David Bramlet based on site visits and both black and white and color aerial photographs converted by our researchers into GIS (ArcInfo) format.

Change Detection

Five alternative methods for change detection were tested and evaluated. Change detection procedures were applied to Sycamore Hills image data from 1996 and 1998. The methods examined include (1) spectral image differencing; (2) change vector classification; (3) NDVI differencing; (4) texture differencing; and (5) post-classification comparison.

Comparative Methodologies

Relative costs and benefits of mapping and monitoring using ADAR-based methods compared to conventional methods were ascertained using actual costs derived from our case studies and from the researchers' familiarity with current costs for generic tasks associated with both methods. The important factors that influence relative benefits and costs were described based on researchers' experience with both conventional and ADAR-based procedures and the quantities of labor, software, hardware, and expertise required to perform specific tasks.

Preparation of Procedures Handbook

Procedures used by researchers to develop image maps from raw ADAR data were carefully documented and described step by step so they can be easily followed by SCE GIAS Lab technicians. The Lab staff was provided with the unprocessed ADAR data used in the study, allowing them to apply the procedures themselves and test the Handbook's utility. Their comments and suggestions were based on their interactive, hands-on review, and are incorporated into the Handbook's final version.

RESULTS

Habitat Mapping

Results of our comparison of methods indicate that third-party geometric processing of ADAR image data is not currently cost-effective. This is due in part to the rapidly evolving and unperfected state of commercially available image processing technologies. Two different third-party providers were asked to provide processing services. The Hidden Ranch data were provided to ID Vision, Inc., which resulted in a product with low positional accuracy, poor documentation, no header or metadata, and slow turn-around. The cost for this low quality product was also relatively low. The Sycamore Hills image data were provided to Vexcel Corporation which also returned a product with slow turn-around and unacceptably low root mean square error.

The five alternative in-house geometric processing procedures were each performed with relative success. The resulting precision varied according to the degree of topographic relief at each of the study sites and according to the quality of available reference data (i.e., GIS data base, DOQQ, existing ADAR image). The preferred method depends on three main variables: site characteristics, available georeference data and mapping objectives. For multi-date monitoring applications, registration to an existing ADAR image map is usually preferable (depending on the quality of the existing image). For other applications, the preferred procedure is to use a high quality georeference data source such as a DOQQ or Digital Elevation Model (DEM), the latter preferably created from aerial photographic stereo pairs. Orthorectification using GPS points can also achieve a high degree of positional accuracy, although collection of GPS points in the field can be time consuming.

Vegetation mapping

Classification of habitat types based on ADAR image data was achieved with a satisfactory degree of accuracy for both the Hidden Ranch and Etiwanda sites. At the Hidden Ranch site, differences between the map produced by field biologists (conventional methods) and ADAR classification are mostly attributable to standard sources of error: mapper subjectivity, image displacement, and limited field verification. These errors were committed to some degree by both methods, the magnitude of error and the differences between them accounting for most of the discrepancies.

Because ADAR-based classification is computer-assisted, classification criteria can be codified to allow for more consistent application, potentially reducing subjectivity error. Image displacement error can be more readily corrected using ADAR-based data through application of softcopy photogrammetry and auto-registration. The need for field verification is common to both methods, although ADAR's ability to image inaccessible areas can reduce the need to visually inspect all areas of a study site.

Change Detection

Land cover changes and/or changes in habitat quality were detected by several of the change detection techniques employed. Results of the study demonstrate that important information about habitat condition and change in condition can be derived from ADAR imagery. Changes at the Sycamore Hills site during the two-year period from 1996 and 1998 that were detected from ADAR imagery include: trail widening, invasion of poison oak into coastal sage scrub, sedimentation in a grassland environment, and regrowth of vegetation in a previously unvegetated area. These results are significant in establishing the potential value of ADAR imagery as a monitoring tool (as distinct from mapping) for habitat management purposes.

Comparative Costs/Benefits

Comparison of relative benefits of using ADAR technology rather than conventional mapping methods indicates that ADAR has distinct advantages over conventional techniques that inevitably translate to greater cost-effectiveness. This is especially the case when:

- ♦ The need for mapping is repetitive, i.e., a need for frequently refreshed data (three to five years, or more);
- ♦ The application calls for landscape level monitoring, particularly monitoring that is specific, purposeful, and related to one or more hypotheses concerning changes in the environment;
- ♦ The data collection will meet the needs of multiple applications and/or parties;
- ♦ The resources to be mapped cover an area of medium to large size (probably at least a few hundred acres);
- ♦ The appropriate facilities and personnel are available to perform image processing functions;

There are several advantages to integrating ADAR-based mapping within a habitat mapping and monitoring program. First and foremost, the vertical imaging perspective from an airborne platform is the only practical means for conducting a wall-to-wall sample of habitat reserves and reserve systems. This, combined with the capability of synoptically viewing all canopy and exposed substrate features at nearly a single instant in time, is complimentary to the more precise and certain observations made at ground-level with lesser spatial coverage. Many of ADAR's benefits derive from the digital nature of its data, permitting image processing, enhancement and classification through computer-assisted procedures. The spatially-explicit, GIS comparability of the data facilitates its integration with other spatial data sets and use in spatially explicit models. The unclassified nature of raw ADAR data further facilitates its use in multiple applications requiring alternative classification scenarios. Finally, the repeatability of ADAR-related procedures (from data collection through pre-processing and classification) offers the potential for cost-effective monitoring of changes in habitat over time and in the long-term.

RECOMMENDATIONS

Results of this study indicate at least three important areas for further research.

(1) Apply image processing and classification techniques to other habitat types, such as

conifer forest, and other woodland and upland plant communities. This would broaden the utility of ADAR and extend its applicability to additional habitat preserves in other geographical regions of California.

(2) Establish a long-term change detection study to further define and refine ADAR's valuable change detection capabilities. Such a study could readily build on the time-series of ADAR image data initiated through funding for the present research. Research objectives would be to identify categories of long-term changes in habitat that can be detected using ADAR, as well as to augment change detection procedures.

(3) Identify ADAR image attributes that correspond to habitat quality. This research task relates to a very important function for habitat management, i.e., monitoring changes in quality of habitat (as distinct from changes in habitat type). Sufficient correlations have not been established between on-the-ground characteristics that determine habitat quality and corresponding features detectable on ADAR imagery.

All three of these research topics would significantly advance ADAR's utility in areas that (based on results of this study) ADAR technology offers the most promise for realizing its cost-effective potential.

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